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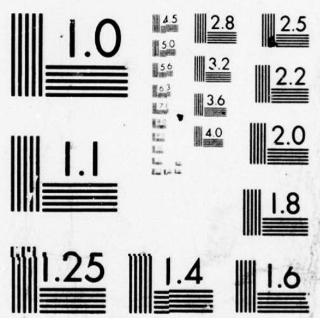

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An Appraisal of Models Used in Life Cycle Cost Estimation for USAF Aircraft Systems

Kenneth E. Marks, H. Garrison Massey, Brent D. Bradley

A Project AIR FORCE report
prepared for the
United States Air Force

Rand
SANTA MONICA, CA. 90406

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Although life cycle analysis is widely used as a management tool, considerable uncertainty still exists about its effectiveness with respect to economic tradeoffs, funding decisions, and resource allocations. This report evaluates some of the most widely used life cycle cost (LCC) models: AFR 173-10 models (BACE AND CACE); the Logistics Support Cost Model; the Logistics Composite model; the MOD-METRIC model; AFM 26-3 Manpower Standards; Air Force Logistics Command Depot Maintenance Cost Equations; the DAPCA model; and the PRICE model. The models are rated within a framework incorporating a set of life cycle cost elements and a set of cost driving factors. Color-coded illustrations summarize the results. The models are shown to have many shortcomings that limit their usefulness for life cycle analyses in which estimates of absolute, incremental cost are required. Specific areas are indentified where driving factor/cost element combinations are not adequately addressed. 120 pp. (Author)

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PREFACE

At the request of the Deputy Chief of Staff for Research and Development, Headquarters United States Air Force, The Rand Corporation has been studying several aspects of the application of life cycle analysis in the Air Force. One objective has been to provide R&D decisionmakers with "yardsticks" for assessing the soundness of life cycle cost estimates—particularly those generated as a consequence of proposed changes in the configuration, capability, or operations and support structure of a weapon in system acquisition. There are few *generalizable* means for evaluating the soundness of the estimates; the estimates stem from a variety of problem settings, most of which are sufficiently different to require unique analysis techniques. Hence the research focused on indirect means of assessment, including: (1) the procedures by which life cycle cost estimates are generated, documented, and presented to decisionmakers; (2) the framework in which cost estimates are expressed; and (3) the effectiveness and utility of the most widely used cost estimating models.

A major part of the research reported here is an evaluation of several aircraft-oriented life cycle cost models and generalized cost estimating techniques. It was not practical to address every extant model; those included here are widely used in the Air Force and are fully representative of the current state of the art. These models are constantly being modified, and they frequently exist in versions not yet documented. The evaluations are based on the most current documentation available, often supplemented by personal contacts with the developers and major users of the models in question.

Originally, the evaluation of life cycle cost models was to have been the principal concern of the study. But shortly after beginning the evaluations, the authors became aware of important deficiencies in the life cycle cost categories in use today. Thus, defining an appropriate set of USAF-specific cost categories and cost elements became an important part of the research.

The frame of reference for the evaluation of life cycle cost (LCC) models and generalized estimating techniques deserves special note. Such models and techniques are applied in many decision contexts: design studies, force sizing studies, source selection, system acquisition reviews, and so forth. For some of these decisions, it may be sufficient that LCC models and estimating techniques indicate the relative cost differences among the available choices. This report, however, is primarily concerned with life cycle cost analysis of proposed changes in the configuration—defined broadly—of aircraft already in development or production. These proposals usually involve substantial incremental investments in R&D or procurement funds that are thought to be justified either for operational reasons or because they will result in lower operating and support costs. In such cases, the acquisition decisionmaker needs estimates of total cost outcomes stated in absolute, not relative, terms. Hence the evaluations are based on the capability of the selected LCC models to generate reliable estimates of absolute incremental costs.

Although intended initially as guidelines and reference materials for use by acquisition managers and others concerned with reviewing and interpreting life cycle cost analyses, the materials presented in the report should be useful as well

to analysts, staff officers, and others concerned with preparing and reviewing life cycle cost estimates.

This research was conducted under the Project AIR FORCE study project "Methods and Applications of Life Cycle Analysis for Air Force Systems."

SUMMARY

Life cycle analysis—the examination of acquisition costs, operations and support (O&S) costs, and system capabilities over the full life of a weapon system—has become an increasingly important and widely applied technique in many different facets of the Air Force system acquisition process. Despite its widespread use, considerable uncertainty exists about the efficacy of life cycle analysis as a management tool, particularly as an aid in evaluating economic tradeoffs (acquisition cost versus O&S cost) and in making funding and other resource allocation decisions that demand reliable and internally consistent estimates of absolute cost.

The main objective of the research reported here is to help system acquisition managers cope with this uncertainty and to furnish them with a means of assessing the completeness and soundness of individual life cycle cost estimates. The means provided is an evaluation of the most widely used life cycle cost (LCC) models: AFR 173-10 models (BACE and CACE); the Logistics Support Cost model (LSC); the Logistics Composite Model (LCOM); the MOD-METRIC model; AFM 26-3 Manpower Standards; Air Force Logistics Command (AFLC) Depot Maintenance Cost Equations; the DAPCA model (Development and Production Costs of Aircraft); and the PRICE model (RCA model for avionics development and procurement cost). Most life cycle analysis studies make use of such models, and hence the strengths and limitations of the model(s) used are important in assessing a proposal that is justified on the basis of a life cycle analysis.

The context of this research was the use of life cycle analysis in support of proposals for major modifications to a previously approved baseline configuration for aircraft systems already in development or production. Such proposals often involve explicit tradeoffs between acquisition cost and downstream (future) O&S costs; and they set the demanding requirement that the estimates of incremental O&S cost be absolute so that they can be compared with acquisition cost estimates. The need for estimates of absolute cost arises in other applications of life cycle analysis as well, and hence the results and conclusions arrived at in the model evaluations are applicable to many problems outside the immediate context of modification proposals.

The models were evaluated within a framework incorporating (1) a set of *life cycle cost elements* which serve as a systematic breakdown of the different types of cost incurred over the life of an aircraft system and (2) a set of *cost driving factors* which provide a generalized means of dealing with various aircraft characteristics and operational and support concepts that influence cost. The life cycle cost elements were defined in terms of the USAF program and budget structure within the general outline of the "Aircraft Cost Element Structure" established by the Department of Defense. The cost driving factors included policies such as mission type, deployment mode, and maintenance concept, as well as reliability/maintainability and physical characteristics of aircraft systems. The models were evaluated by examining each driving factor/cost element combination and assessing the ability of the models to predict the effect (if any) on the cost element of a change in the driving factor. Figure S.1 summarizes the results of the evaluations. The color-coded ratings in the cells of the matrix indicate, for each driving factor/cost ele-

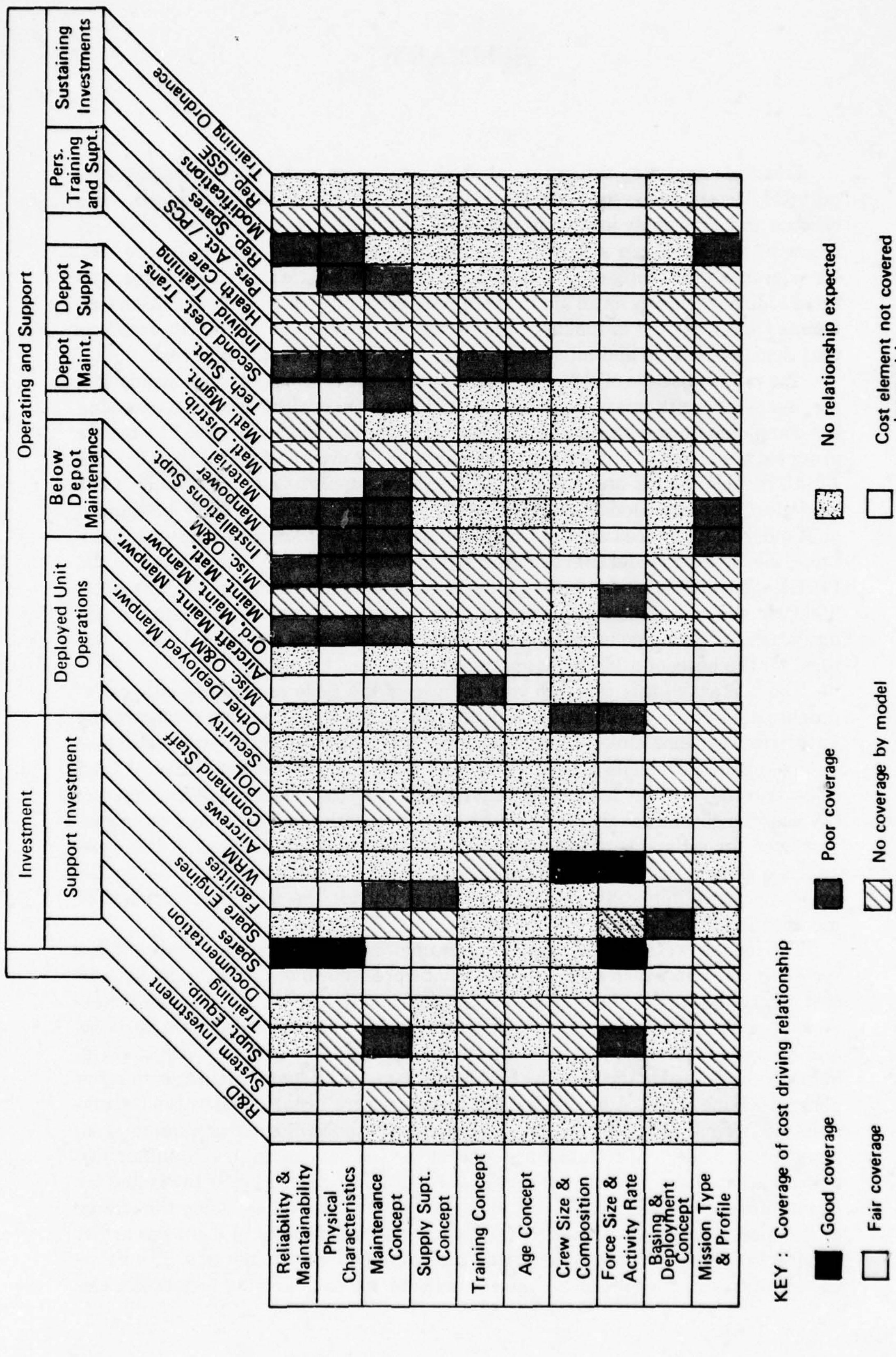

Fig. S.1—Overall coverage of the cost models

ment combination, the quality of coverage provided by the model that does the best job of predicting the cost implications for that combination.

The cost models reviewed have substantial differences in their intended use, coverage of cost elements, and the strengths and weaknesses of their estimating techniques. The evaluations show that there are few areas where the models—individually or in combination—are capable of producing reliable estimates of the absolute, incremental costs of a proposal. And there are many areas where the models provide no useful cost estimating capability. The particular driving factor/cost element combinations that are most important will vary from one problem to another. More than half of the relevant combinations are either not dealt with at all by the models or are handled in a manner that appears to be completely unrelated to the real cause and effect relationships. Hence, in most cases the models cannot serve as a firm basis for life cycle cost estimates without additional supporting data and analyses. O&S cost estimates produced by the models often serve only as relative cost indicators, resembling "figures of merit" rather than predictions of dollar costs that can be observed and measured in the future. These figures of merit may be useful for examining relative comparisons of the O&S costs of alternatives in some applications, but since their relationship to real O&S costs is obscure, they are rarely helpful in determining whether an incremental investment is economically justified by future "savings" in operating cost.

The principal message that emerges is that current LCC models have many shortcomings that limit their usefulness for life cycle analyses of major modification proposals or other applications where estimates of absolute, incremental cost are required. Specific areas are identified where driving factor/cost element combinations are addressed poorly (or not at all) by the models. An awareness of these deficiencies should (1) aid decisionmakers in understanding the degree of uncertainty in an estimate; (2) help analysts to decide where estimates provided by the models need to be supported by additional analyses or empirical evidence; and (3) indicate the principal areas where improvements in cost data bases and/or research and development of improved cost estimating methodologies are needed.

Although estimating difficulties exist for both acquisition and O&S costs, the latter are particularly troublesome in most life cycle analyses. In developing improved estimating techniques, the first priority should be given to more realistic representation of O&S costs.

Historical data in support of LCC estimates have been difficult to find, largely because the cost categories used in LCC models are incompatible with the functional and accounting categories used to record manning and cost information. The life cycle cost element definitions developed for this research provide a means of alleviating much of that difficulty. Adoption of these definitions—or of a similar set based on Air Force financial and resource management categories—should provide a sounder basis for LCC estimates that can be realistically traced from initial estimate through full implementation of a proposal.

In addition to the use of a single, well-defined cost element structure, the other major general improvement that should be made in LCC modeling is improved sensitivity to cause-effect relationships. This requires both the identification of actual causal relationships between cost driving factors and elements of cost, and the recognition that organizational, operational, and support concepts are important cost drivers in addition to the aircraft system's physical characteristics.

Allocation methods that simply distribute costs in proportion to a convenient system characteristic (and which have little or no established relationship with the real cost driving factors) should be avoided. If LCC modeling is used in evaluating alternative hardware designs, visibility at the subsystem and component level is required. But the component-level visibility that is available in existing models should be combined with a more thorough consideration of the organizational, operational, and support policies that make up a total weapon system.

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In preparing this report, we received assistance and useful comments from Captain John Wallace of Hq Air Force Logistics Command, Perry Stewart and Russell Genet of AFLC's Air Force Acquisition Logistics Division, and Jack Gibson of the Aeronautical Systems Division, Air Force Systems Command. Rand colleagues Robert Butler and Elwyn Harris provided helpful reviews in the final preparation of the report, and Giles Smith provided assistance, comments, and reviews from the inception of the research.

CONTENTS

FIGURES

TABLES

GLOSSARY

AFIF	Air Force Industrial Fund
AFLC	Air Force Logistics Command
AGE	Aerospace ground equipment
AMST	Advanced Medium STOL Transport
ANG	Air National Guard
ASIF	Airlift Service Industrial Fund
BACE	Budgeting Annual Cost Estimating model
BOS	Base Operating Support
CACE	Cost Analysis Cost Estimating model
CAIG	Cost Analysis Improvement Group
CCT	Combat crew training
CE	Cost element
DAPCA	Development and Production Costs of Aircraft
DMIF	Depot Maintenance Industrial Fund
EDS	Engine diagnostic system
EEICS	Elements of expense investment codes
FC	Function codes
F&FP	Force and Financial Program
FH	Flying hours
FLU	First line unit
FNIH	Foreign Indirect Hire
GFAE	Government furnished aerospace equipment
LCC	Life cycle cost
LCOM	Logistics Composite Model
LRU	Line replaceable unit
LSC	Logistics Support Cost model
MDS	Mission-Design-Series
METRIC	Multi-Echelon Technique for Recoverable Item Control
MFP	Major force program
MTBF	Mean time between failures
NRTS	Not reparable this station
OJT	On-the-job training
O&M	Operations and Maintenance
O&S	Operations and Support
PCS	Permanent change of station
PE	Program element
PME	Precision measuring equipment
POL	Petroleum, oil, and lubricants
POM	Program Objective Memorandum
POMO	Production Oriented Maintenance Organization
PPB	Planning, Programming, and Budgeting
PPE	Primary program element
PRICE	Programmed Review of Information for Costing and Evaluation

R&M	Reliability and maintainability
RPMA	Real Property Maintenance Activities
SPO	System Program Office
SRU	Shop replaceable unit
TASC	The Analytical Sciences Corporation
UE	Unit equipment
UPT/UNT	Undergraduate pilot training and undergraduate navigator training
USAFR	Air Force Reserve
WRM	War reserve material
WRSK	War readiness spares kit

I. INTRODUCTION

In recent years life cycle analysis has gained considerable attention as an aid to decisionmaking in the Air Force system acquisition process. This attention derives from concern over high operating and support (O&S) costs for both current and proposed weapon systems and from a desire to free O&S resources wherever possible for force modernization. It is generally believed that operating and support costs can be influenced significantly by system design, performance, and operational characteristics and by other factors that may be controllable by management decisions during system acquisition. Life cycle analysis serves as part of a control mechanism by providing system acquisition managers with insights about the full cost consequences of acquisition management decisions. In particular, it provides an approach for explicitly striking a balance among system capability objectives, near term acquisition cost, and downstream (future) cost for operation and support.

Life cycle analysis is applied—almost routinely—to many different facets of the Air Force system acquisition process, including design/configuration decisions and cost-performance tradeoffs; source selection for both primary systems and components; program planning, budgeting, cost tracking, and management review; and support system planning. But despite its widespread and varied application, life cycle analysis is not yet a finished and fully effective management tool. The conceptual framework for life cycle analysis has developed in patchwork fashion and is still incomplete. Policy guidance for its use and purpose needs to be more fully explicated. Important questions remain about the preferred organizational and procedural arrangements for preparing, corroborating, documenting, reviewing, and acting upon life cycle analysis studies. The methodology of life cycle analysis is also incomplete. And while a wide array of life cycle cost (LCC) models are in common use, data to support them and conventions to guide their application are lacking.

The practical significance of these limitations varies with the nature of the system acquisition problem to which life cycle analysis is applied—and some of the limitations are gradually being overcome. But for now, many acquisition managers lack confidence in the results of analyses as currently performed and are uncertain about the efficacy of life cycle analysis techniques. This uncertainty is particularly significant when life cycle analysis is used as an aid in economic tradeoff evaluations (acquisition cost versus O&S cost) and in funding and other resource allocation decisions that demand reliable, internally consistent estimates of absolute cost. Applications in which this type of estimate is needed were the principal focus of the research reported here.

The main objective of this report is to help system acquisition managers cope with the uncertainties arising from the limitations of current life cycle analysis practices and to furnish them with a means of assessing the completeness and soundness of individual life cycle cost estimates. The means provided is an evaluation of the most widely used life cycle cost models and other formal estimating methods applicable to aircraft systems.

Life cycle analysis studies may employ a variety of both formal and ad hoc methods for assessing costs and other problem attributes, but most studies use life

cycle cost models or other formal cost estimating techniques (called collectively "models" in this report). Hence an understanding of the appropriateness, the strengths, and the limitations of the model(s) employed is important in establishing the credibility of a proposal based on life cycle analyses. (It is equally important that any ad hoc methods employed in a study be understood—but of course such methods cannot be evaluated a priori.)

The models[1] included in our evaluation are

- AFR 173-10 models (BACE and CACE)
- Logistics Support Cost model (LSC)
- Logistics Composite Model (LCOM)
- MOD-METRIC model
- AFM 26-3 Manpower Standards
- Air Force Logistics Command (AFLC) Depot Maintenance Cost Equations
- DAPCA model (Development and Production Costs of Aircraft)
- PRICE model (RCA model for avionics development and procurement costs)

All but the DAPCA and PRICE models are oriented to O&S cost, the most troublesome aspect of life cycle cost when economic tradeoffs are of concern and when estimates of absolute cost are required.

Our evaluations of these models should furnish acquisition managers and cost analysts a basis for (1) determining whether the predicted cost consequences of a proposal are consistent with current knowledge of how costs are actually driven and incurred in the Air Force, and (2) identifying areas where weaknesses in the model being used create a need for additional information to support the cost estimate. Analysts can also use these evaluations to determine which, if any, cost model is best suited to a given life cycle analysis problem.

The models are evaluated in a defined framework of life cycle cost elements and cost driving factors.[2] The life cycle cost element definitions provide an objective frame of reference and serve as a link between life cycle analysis techniques and the programming and budgeting processes used to implement decisions in the Air Force. This important link has been missing in most applications of life cycle analysis. Therefore we propose that the Air Force adopt our definitions (with such modifications as may be needed) as the official set of cost element definitions for life cycle analysis studies of aircraft systems.

Although this report focuses on the capabilities of LCC models, we recognize that the relevancy and quality of the input and reference data available to support

[1] Some models—particularly the LSC model and the BACE and CACE models—have given rise to variants that are also employed in life cycle analysis. The models tend to be in a constant state of change as new knowledge is gained and improvements are incorporated. These variants and changes could not be treated in depth here, but we note some model capabilities that are products of the model variants rather than of the original model.

[2] Battelle Laboratories recently undertook a somewhat related effort with a substantially different focus under the sponsorship of AFLC and the Air Force Avionics Laboratory. (See Thomas R. Cork and David W. Welp, *Definitions of a Systematic Cost- and Logistics-Effectiveness (SCALE) Procedure*, Battelle Columbus Laboratories, January 12, 1976; T. R. Cork, *Report on the Selection of Models for a Set of Interactive Cost Models*, Battelle Columbus Laboratories, September 13, 1976.) The study concentrated on finding the most satisfactory combination of existing models (including some of those discussed in this report), in an interactive computer mode, to represent the relationships among logistics parameters, mission performance, and cost. The existing models were assumed to provide adequate capability; the study did not evaluate model weaknesses or sensitivity to real cost driving factors.

the model's use are important factors. The scarcity of reliable LCC data is a problem that pervades life cycle analysis in general; perhaps more important, some of the principal estimating methods (particularly for O&S costs) are based on theoretical concepts that have no empirical basis. With enough time and resources, current limitations of generalized LCC data can sometimes be alleviated by assembling a data base for a specific life cycle analysis study. Hence data problems are often context specific, and it is difficult to reach any useful general conclusions about their effect on life cycle analyses. Although we point out some areas where problems arise because data to provide an empirical basis for estimating relationships are lacking, we do not provide a comprehensive view of the LCC data problem. This subject will receive closer attention in future research.

ORGANIZATION OF THE REPORT

Section II discusses the specific context and the research approach taken in evaluating the individual cost models and defines the set of cost driving factors and the life cycle cost elements used. Complete definitions of the LCC elements are presented in Appendix A, along with a discussion of the USAF program and budget structure used in establishing the definitions.

The model evaluation results are presented in Sec. III. Each model's estimating methodology is first described, followed by a color-coded driving factor/cost element matrix showing overall results of the model evaluation. For cost elements the model addresses, the matrix cells are color-coded to evaluate the model's ability to handle the expected relationship between the cost driving factors and the costs of indicated cost elements. Examples for each model illustrate the reasons for assigning particular evaluations to the cells. A complete listing and discussion of the evaluations and the reasons for assigning them are provided in Appendix B. Thus Sec. III is an overview of each model's capabilities, while Appendix B provides additional details and backup information for those interested in examining specific relationships.

Section IV presents our conclusions regarding the use of life cycle cost models as they exist today, with suggestions for improving the way in which the models' results are presented to decisionmakers. Finally, some improvements are suggested to remedy the observed deficiencies in current estimating techniques.

II. RESEARCH APPROACH AND EVALUATION FRAMEWORK

CONTEXT

Many models described in this report are routinely used in more than one type of cost analysis application—a factor that contributes to uncertainty about their suitability for life cycle analysis problems. We do not attempt to deal with all uses of the models. The concerns that motivated this research centered on the evaluation of configuration[1] change and modification proposals for aircraft systems in development (with a baseline design already established), in production, or already in operational use. The requirements and implications for cost estimating that this application entails will be shown to extend to other types of life cycle analysis problems. Modification proposals are an important part of the design/configuration decisions that significantly affect system acquisition. Two recent examples include: (1) a proposal to modify the baseline design of the F-100 turbine engine—used in both the F-15 and F-16 aircraft— to incorporate an engine diagnostic system (EDS) and (2) a proposal to eliminate the planned navigator crew position in the Advanced Medium STOL Transport (AMST) aircraft and to incorporate additional avionics to substitute for the navigator. Both proposals included a reduction in life cycle cost in their list of anticipated benefits.

Typically, major modification proposals

1. Involve implicit or explicit tradeoffs between cost and performance or capability, and between acquisition cost (development and procurement) and O&S cost.
2. Require review and approval by acquisition managers above the level of the system program office.
3. May involve significant budgetary considerations.
4. Require estimates of absolute, not relative, cost.

In the main, major modifications proposals provide a demanding context in which to evaluate the capability of life cycle cost models. From a *cost* viewpoint, these proposals resemble investment decisions—a near-term acquisition cost is traded for a reduction in downstream O&S costs. In the case of the EDS, the tradeoff is between the acquisition cost for the EDS and the expected savings in engine operating and maintenance costs. In the case of the AMST, the tradeoff is between the avionics acquisition cost and the savings in navigator pay, support, and training cost (net of any additional cost for avionics maintenance and support). In these applications, acquisition and O&S costs must be stated in comparable terms. In many life cycle cost estimates, however, they are not. In particular, acquisition costs tend to be absolute in the sense that they can generally be tracked as accounting entities throughout the course of a program. On the other hand, O&S costs are not usually absolute in the same sense—the actual *cost* savings resulting from the

[1] "Configuration" is used broadly to connote both air vehicle characteristics and the operational and support characteristics of the aircraft weapon system.

design change (as distinct from savings in repair hours, failure frequencies, or other such measures) are usually not observable. In fact, analysts often disagree about the operating and support costs of current weapon systems, subsystems, and components, depending on the model or convention chosen to describe the costs.

This need for O&S cost estimates that are absolute—in the sense that they can be compared with and traded for acquisition costs—had a major effect on our assessment of the cost models' capabilities. Estimates of absolute cost are usually required in major modification proposals. In other life cycle analysis applications, estimates of relative costs—not absolute costs—may sometimes be sufficient. However, conditions that permit the use of cost estimates that are not absolute in the above sense are rather special. If the major cost differences between options come wholly or substantially from a single cost element or from a set of cost elements with comparable depth of coverage and estimating techniques, relative costs may be a suitable measure for comparing options. But in virtually any class of decision problems, the mix of cost elements may vary among the alternatives. Hence, although we generally discuss the results of the model evaluations as they relate to design changes and modification proposals, they are equally valid for other types of life cycle analysis problems that need reliable, consistent estimates of absolute cost.

APPROACH

In general, proposals for aircraft design changes arise when (1) a deficiency in the planned capability of the system needs to be corrected; or (2) a means has been found (or is thought to exist) to make improvements in system capability beyond that originally planned; or (3) there is an opportunity to save acquisition or downstream O&S costs. In each instance the emphasis is on a *change* in the currently planned design of the hardware and/or some aspect of the aircraft's operations and support concepts. The effects of such a change might well be masked by the uncertainty surrounding the customary "total" life cycle cost estimate. What is needed is a reliable estimate of the *change* in total life cycle cost that will result from the proposed design change. This requires a full description of the design change and a life cycle cost model that (1) has a high degree of sensitivity to system/subsystem parameters; (2) represents with reasonable fidelity the cause and effect relationships determining cost outcomes; and (3) provides a reliable estimate of total incremental cost.

To provide generalized evaluations of the models in this context, the elements that characterize a design change (the inputs) and the costs that result from such a change (the outputs) need to be broken down into generalized components. For the input side of this relationship we defined a set of "cost driving factors" that included physical parameters of the aircraft, reliability and maintainability characteristics, and operations and support concepts. In principle, any proposed change to the configuration of an aircraft system can be translated into changes in one or more of these factors. Hence they provide a means of dealing with any specific change proposal in terms of its general components.

On the output side is a set of life cycle cost elements. It was evident from the first that the models examined were not consistent in their definition and coverage

of cost elements. In fact, there had not been a commonly accepted life cycle cost element structure until the recent "Aircraft Cost Element Structure" established by the DoD Cost Analysis Improvement Group (CAIG)[2] as the official set of cost elements for analysis of aircraft systems. But even the CAIG's definitions fail to establish an objective, unambiguous means of determining exactly which costs should be included in a particular element; furthermore, analysts may interpret the definitions differently.

Because a complete, fully defined set of cost elements was a prerequisite to our evaluation of the models, an important part of our effort went into defining Air Force-specific LCC categories. Our categories are essentially the same as those used in the CAIG structure, but we defined their contents in terms of USAF Force and Financial Program (F&FP) program elements and USAF budget appropriation categories to provide a more objective basis for the cost element definitions and to establish the relationship between cost categories for life cycle analysis and the categories on which the Air Force's system of allocating and managing resources is based.

The set of cost driving factors and the set of life cycle cost elements can be combined and arrayed in a matrix format to provide a useful structure for evaluating the cost models. Each cell of the matrix represents the actual (or expected) relationship between a specific cost driving factor and a specific cost element. In evaluating the cost models, we considered each such driving factor/cost element combination—excluding those for which no cost driving relationship would be expected—and we asked how well a given model could perform in estimating the change in cost (within the indicated cost element) produced by a change in the driving factor. The evaluation matrix and the criteria for judgment in the evaluations are discussed further at the end of this section after we define the cost driving factors and life cycle cost elements as we have interpreted them in the cost model evaluations.

COST DRIVING FACTORS

The concept of cost driving factors encompasses weapon system characteristics, operating and support policies, and characteristics of the world in which the system is to operate. Cost models employ various types of inputs describing a weapon system as direct cost driving factors in their functional relationships. In this study, we are primarily concerned with the operations and support policies and hardware characteristics that acquisition managers might want to examine during the development and production of an aircraft system. Although there is no officially defined set of cost driving factors, an examination of various life cycle analysis studies (such as design change proposals of the type that motivated this research) suggests three broad categories: aircraft characteristics, support concept, and operations concept. Within these categories, the possibilities for specifying individual driving factors

[2] N. E. Betaque, Jr., and M. R. Fiorello, *Aircraft System Operating and Support Costs: Guidelines for Analysis*, Logistics Management Institute, March 1977, p. 28. The report, which deals at length with operating and support cost estimating in support of major system procurement decisions, is referred to here as the CAIG Guide, because it was commissioned by the OSD Cost Analysis Improvement Group for use in a forthcoming revision of the "Cost Development Guide for Aircraft Systems" originally published by the CAIG in 1974.

are almost unlimited. For purposes of this study, we chose ten subcategories of driving factors, which are listed in Table 1. This list is not exhaustive; for example, acquisition strategy (use of prototypes, phased procurement, etc.) can also have an important influence, primarily on development and procurement costs. Such factors, however, are generally unique to each development program and are fixed at the beginning of the program. The factors listed in Table 1 apply primarily to changes *after* an aircraft development program is initiated. The relationship between costs and the system characteristics these factors describe may not be readily demonstrated by empirical evidence. Some of the factors are commonly recognized as important and are often included in LCC models (physical characteristics, force size, and activity rate), but others are not (training concept, basing and deployment concept). Furthermore, these factors are partially interdependent. Changes in aircraft characteristics, for example, often induce changes in or place constraints on support and operations concepts.

Table 1

COST DRIVING FACTORS

```
Aircraft characteristics
   Reliability and maintainability
   Physical characteristics
Support concept
   Maintenance concept
   Supply support concept
   Training concept
   Aerospace ground equipment (AGE) concept
Operations concept
   Crew size and composition
   Force size and activity rate
   Basing and deployment concept
   Mission type and profile
```

Aircraft Characteristics

In general usage, *reliability and maintainability* (R&M)—usually expressed in terms of mean failure rates and mean repair times—is a characteristic of the system and its environment that is a joint product of several of the driving factors defined here, including support concept, maintenance concept, activity rate, and mission profile, as well as the aircraft (hardware) reliability and maintainability. The R&M cost driving factor is used here in the restricted sense of *aircraft* R&M—physical and design characteristics of the aircraft and components that affect overall system R&M. Failure frequency is the most often used measure of reliability, but failure mode and failure mechanism are also reliability characteristics that can affect cost. The concept of reliability as a driving factor also includes such general design characteristics as the use of redundancy as a means of achieving high system reliability. The maintainability characteristics of a design are manifested in the time and manpower needed to detect, diagnose, and correct failures and to perform individual tasks of preventive maintenance and servicing. Repair times and man-hours per repair are frequently used maintainability parameters.

In addition to R&M, a number of *physical characteristics* of the aircraft can have an effect on LCC. Overall measures such as weight, size, and speed are usually recognized as important cost driving characteristics of aircraft. Others that affect LCC and can serve to distinguish between designs at a more detailed level include the number of parts, avionics power requirements, type of structural material, use of internal or external stores locations, the number and type of engines, and the degree of commonality with other weapon systems.

Aircraft performance characteristics are not explicitly included in this list of driving factors. Performance is considered in this framework to be derived from the mission for which the aircraft is procured and the physical characteristics of the design chosen as the means to accomplish the mission. Payload, for example, is a function of the intended mission type (cargo, fighter, bomber) and the size, weight, engine thrust, and other physical characteristics of the aircraft. The effect of performance characteristics on cost is thus accounted for implicitly.

Support Concept

The support concept consists of policies related to the provision of maintenance, supply, training, and aerospace ground equipment (AGE) support for a weapon system. The *maintenance concept* is a set of policies that sets constraints or requirements on the manner in which maintenance is conducted. These policies vary from program to program, depending on decisions made by the System Program Office (SPO) and other organizations. What is established as a "requirement" in the maintenance concept for one program may be left, on another program, as a subject for tradeoff studies. Typical elements of a maintenance concept include:

1. Maintenance locations and sources (flight line, base shops, depot, contract, interservice).
2. Base-level maintenance organization.
3. Levels of maintenance for each hardware level.
4. Base-level maintenance practices (bench checks, use of special tools, use of specialists, etc.).
5. Failure diagnostic techniques (automatic, built-in, etc.) and hardware level to which applied.
6. Scheduled and special inspection types, intervals, and scope.
7. Intervals, scope, and methods of depot repair.

Air Force tests have demonstrated that changes in maintenance concept can influence maintenance cost. For example, in a recent unpublished PACAF study of the centralized intermediate maintenance concept,[3] savings were indicated by increases in the mean time between removals for items repaired at the central facility and by reductions in the number of items that needed to be returned to the depot for repair.

The *supply support concept* is composed of policies that determine where and in what quantity spares and repair parts are stocked, who controls them, and how they are distributed. Stock points may be collocated with using activities, centralized, or both. Stock levels are determined by rules governing safety stock and reorder quantities. Centralized supply support can be provided by the Air Force or

[3] All intermediate-level component repair for an aircraft system performed in one location.

by a contractor. The supply support concept is generally related to the maintenance concept.

The *training concept* establishes the methods used to provide required training. It may specify whether training is to be accomplished in a classroom or on the job, or both. Classroom instruction may be provided by central training facilities or by field detachments. Subject matter may be general or specialized. Flight training policies may control the use of flight simulators as an alternative to flying.

The *AGE* or *support equipment concept* determines which maintenance and servicing tasks are eligible for accomplishment by or with the help of support equipment. The support equipment concept may place constraints on the use of new or peculiar support equipment as opposed to existing or common support equipment. Required support equipment quantities may be driven by a requirement to meet a specified support equipment availability requirement or by a specified limit on the number of support equipment types or individual support equipment items. The AGE concept is related to and partially dependent on the maintenance concept.

Operations Concept

Policies that determine how the aircraft is used constitute the operations concept. *Crew size and composition* policies establish how many crew members are required on each aircrew and what functions they need to perform. The extent of aircraft operations depends on a combination of *force size and activity rate.* Activity rate is a general term referring to the level of operations of an individual aircraft; any of several measures of activity may be significant, including flying hours, sorties, alert rate, and wartime flying rate. A requirement to maintain a certain level of aircraft "availability" can be considered as another measure of "activity." The concept of force size is assumed here to include number of unit equipment (UE) aircraft, squadrons or wings, and aircrew ratios.

The *basing and deployment concept* encompasses aspects of the operations concept pertaining to peacetime and wartime locations of units and the size of units occupying each location. The basing posture involves such parameters as number of bases, number of aircraft per base, base locations, and size of bases (in terms of personnel and facilities). The effect of basing posture on O&S cost can be seen, for example, in the economies of scale in bomber/tanker manning requirements for a "double" wing (i.e., two squadrons each of bombers and tankers) as compared with single wing requirements. Deployment policies determine the number and size of deploying units (in wartime), deployment site locations, and the frequency and duration of peacetime deployments. Training concept and activity rate are related factors in peacetime deployment policies.

The *mission type and profile* of an aircraft include two other important aspects of the operations concept. Fighter, bomber, cargo, tanker, and trainer have different types of missions; hence they use different organizational structures, and they operate differently (e.g., readiness for wartime deployment for tactical fighters, versus normal peacetime operations for trainers). Mission profile—which refers to the combination of altitudes, speeds, g-loads, etc. encountered in a sortie—may vary for an aircraft of a given type (e.g., close air support versus air interception for a multipurpose fighter). The mix of mission profiles can affect fuel consumption and the rate at which subsystems are exercised (and must be maintained).

Factors Not Included

This list of cost driving factors excludes certain forcewide policies which, although they may significantly influence cost, are only slightly, if at all, subject to change by decisions at the weapon system level. Maintenance skill levels available, for example, have an effect on the types of tasks that maintenance personnel can be expected to perform; but skill levels are a characteristic of the manpower pool as a whole and cannot be quickly changed to accommodate a particular weapon system. They are determined by recruiting results, the effectiveness of pre-service schooling, and the effectiveness of Air Force training. Statutory restrictions on numbers and distribution of personnel by skill level or grade are additional influences that must be accommodated. The amount of direct productive time that can be expected from an individual has a strong effect on the manpower needed to accomplish a given workload. The Air Force has a number of wartime and peacetime standards for man-hour "availability" (i.e., fraction of time available during a workweek for regular duty requirements) that apply forcewide and constrain the relationship between workload and manpower requirements for all systems.

Air Force total budget levels for some categories of expenditures may be set or constrained by budgeting processes separate from the establishment of individual system requirements (e.g., a constraint on the total budget for replenishment spares). In such cases, a change in the cost driving factors for a single weapon system may have no visible effect on the total budget, although the change might still be reflected in the portion of the total attributable to the weapon system.

LIFE CYCLE COST ELEMENTS FOR USAF AIRCRAFT

Virtually all life cycle cost estimates are divided at some level of the estimating process into a set of cost elements. One major problem in interpreting and evaluating cost estimates is that there is little agreement as to what elements constitute a "complete" life cycle cost estimate—or what items should be included in individual cost elements. Consequently, estimates prepared by different analysts using different models or using different variants of the same model may show substantial disagreement even when the same basic inputs are used by all. For the most part, the cost models examined in this study were formulated before life cycle analysis gained prominence, and they generally cover only those cost elements that were assumed to be variable in the applications for which the models were originally designed. That is, cost elements that are not covered are *implicitly* assumed to remain fixed among all the alternatives that are to be examined. This implicit assumption is not often examined closely; and given the wide variety of possible applications of life cycle analysis, more extensive and explicit coverage of costs is needed.

Both the extent of cost coverage and the contents of each life cycle cost category must be specified if these categories are to serve as an objective frame of reference. The cost element structure we use is based on CAIG's aircraft cost element structure, which includes both acquisition and O&S cost elements but is much more disaggregated for the latter. Table 2 lists the cost elements we use.[4] Categories

[4] See Betaque and Fiorello, op. cit.

Table 2

USAF Aircraft Life Cycle Cost Categories

- Research and Development
- Investment
  - System Investment
  - Support Investment
    - Support Equipment
    - Training Equipment and Services
    - Documentation
    - Initial Spares and Repair Parts
    - Spare Engines
    - Facilities (Non-production)
    - War Reserve Material (WRM)
      - *Spares and Repair Parts[a]
      - Munitions
      - Missiles
      - *Tanks, Racks, Adapters & Pylons[b]
- Operating and Support
  - Deployed Unit Operations
    - Aircrews
    - Command Staff
    - POL
    - Security
    - Other Deployed Manpower
    - *Miscellaneous O&M (Personnel Support)[c]
  - Below Depot Maintenance
    - Aircraft Maintenance Manpower
    - Ordnance Maintenance Manpower
    - Maintenance Material
    - *Miscellaneous O&M (Personnel Support)[c]
  - *Installations Support[d]
  - Depot Maintenance
    - Manpower
    - Material
  - Depot Supply
    - Material Distribution
    - Material Management
    - Technical Support
  - Second Destination Transportation
  - *Personnel Training and Support[e]
    - Individual Training
    - Health Care
    - *PCS Travel (Personnel Activities)[f]
  - Sustaining Investments
    - Replenishment Spares
    - Modifications
    - Replenishment Ground Support Equipment
    - Training Ordnance
      - Munitions
      - Missiles

NOTE: Asterisk denotes category that has been modified from the CAIG list.

[a] WRM spares and repair parts are combined into a single element to conform to management practices and data sources.

[b] Sonobuoys are deleted as inapplicable to the Air Force.

[c] The CAIG "Personnel Support" subcategory, under the Deployed Unit Operations and Below Depot Maintenance categories is renamed Miscellaneous O&M to reflect the broader coverage of the element.

[d] The subelements under Installation Support are not used, because this higher level element is sufficient for weapon system cost estimating.

[e] The costs in the CAIG "Personnel Support" subcategory under Personnel Training and Support are more appropriately treated as part of the total O&M costs of the Individual Training and Health Care elements than as a separate element. Therefore, the Personnel Support subcategory is eliminated and the costs merged into the other two subcategories.

[f] The cost category title "Personnel Activities" is changed to "PCS Travel" to indicate the limited nature of the coverage of this category.

marked with an asterisk are somewhat modified from those in the CAIG list to conform more closely to Air Force financial management practices and constraints.

Although the CAIG Guide defines each cost element in terms of the commodities and/or services it is supposed to cover, the definitions still leave room for interpretation. Thus objective measures of cost for some elements are difficult to identify. To alleviate this difficulty, to use terms familiar to acquisition managers, and to get closer to actual Air Force processes for resource allocation, we drew on the categories of resources and costs used in the Air Force programming and budgeting system. We wanted to define LCC elements that could be followed continuously from cost estimate, through the programming and budgeting actions needed to implement a life cycle analysis proposal, to the recording of actual experience. It was not possible to do this perfectly because Air Force programming, budgeting, and accounting categories do not always identify costs to weapon systems. Also, the nominal categories used for programming sometimes conflict with the categories actually used in managing and accounting for costs. Nonetheless, with enough added information, objective definitions reflecting the actual allocation of manpower, budget dollars, and other resources can be provided for most of the elements.

Our cost element definitions use program information from the USAF Force and Financial Program (F&FP), which divides Air Force activities and organizational units, manpower authorizations, and budget costs into ten major force programs (MFPs). Each program element (PE) within the MFPs is associated with specific equipment, facilities, manpower, and costs. The costs are divided into appropriation categories and cost elements (CEs) within each appropriation. In most cases we can define CAIG Guide categories directly in terms of F&FP PEs. For the direct costs of weapon systems this can be done readily, but for indirect support costs, PE definitions alone are not sufficient to define the costs attributable to a specific system. It is possible, however, to specify the PEs that cover forcewide total costs in each support category. The identification, within each support category, of fixed costs and costs that vary with changes in weapon systems or force levels is usually handled by the use of conventions or rules of thumb that associate a "support tail" cost with the direct resource requirements of a weapon system.

The major direct costs of a weapon system are usually identified in the F&FP with a weapon system program element or primary program element (PPE)—for example, F-15 Squadrons. Also, for most aircraft systems, the direct O&S cost of units engaged in combat crew training (CCT) activities[5] is identified with a training PE. For example, Training—Tactical Air Forces includes CCT costs for all tactical aircraft systems. Together the PPE and training PE contain essentially all the costs that should be covered in the life cycle cost elements Research and Development, System Investment, Support Investment (except for a portion of War Reserve Material Costs), Deployed Unit Operations, Below Depot Maintenance, and Sustaining Investments (except for Training Ordnance).

Other life cycle cost elements can be identified with other specific program elements, as explained in Appendix A. These other costs are primarily indirect, general support costs, and the program structure does not provide an unequivocal means of associating specific costs with specific weapon systems. For some of these

[5] Combat crew training pertains to the training of aircrews to fly a particular type of aircraft. It does not include undergraduate flight training, which is intended to teach individuals the basics of flying.

costs (e.g., for Depot Maintenance), there are accounting and/or data systems that provide a means of identifying some of the cost to specific weapon systems, subsystems, or components. But for most of the support cost categories, one must resort to a convention or rule of thumb for (1) isolating that portion of the cost that is variable with weapon system demands and (2) specifying the rate at which the support costs change with changes in the weapon system. A fully objective measure of cost cannot be identified in such cases, but it is possible to be explicit about the rules of thumb and to specify the area of support cost they are intended to represent.

Table 3 lists the life cycle cost elements used in this study along with the program elements and appropriations/CEs (within the stated program elements) that we have associated with each LCC element. Appendix A provides an expanded discussion of the program structure and the appropriation structure as they pertain to these LCC element definitions. It also provides full definitions of the LCC elements in commodity terms (corresponding to the CAIG definitions) integrated with the program element and appropriation classifications. Many of the life cycle cost categories are mapped directly into a subset of appropriation CEs within specific program elements. To a major extent these definitions make it feasible to estimate, budget, and track life cycle costs in consistent terms.

The definitions shown here for indirect support cost categories (e.g., Installations Support, Depot Supply, Personnel Support and Training) are intended to identify the forcewide costs in these categories within which the "variable" weapon system costs are contained. As noted above, some set of conventions or rule of thumb is needed to identify the portion of these costs attributable to a weapon system. No standard conventions exist for some of these categories; and for others, different models use different rules. One can judge whether or not a particular convention is reasonable, but it is not usually possible to determine whether or not it is correct in an absolute sense. The derivation of currently used rules of thumb is often not known; and in any event, the LCC element definitions presented here are, in virtually all cases, the first attempt at establishing explicit relationships between LCC elements and the program element and appropriation breakdowns used in the Air Force's normal programming and budgeting procedures. Therefore, it is likely that most of the factors used currently for estimating indirect support costs are not based on any corresponding set of PE and appropriation categories.

FRAMEWORK FOR THE ANALYSIS

The combinations of cost driving factors and cost elements, as described above, are the discrete elements that must be examined and evaluated for each model. The driving factor/cost element matrix is used to summarize and display the results of these evaluations. Of course, some cells in the matrix represent combinations for which no cost driving relationship—or only a very weak one—is expected (e.g., between aircraft reliability/maintainability and aircrew costs). The matrix is shown in Fig. 1. Cells for which little or no relationship is expected are shaded. The remaining (blank) cells must be examined for each cost model. Appendix B explains the basis for the assumed cost driving relationships for applicable cells and the reasons for assuming no relationship for the others.

Table 3

LIFE CYCLE COST ELEMENT DEFINITIONS FOR TYPICAL AIRCRAFT SYSTEM

Cost Category	F&FP Program Element	Appropriation/Cost Element
Research and Development	PPE (MFP 1,2,4) or MFP 6 (if prior to prod. approval)	3600-RDT&E
Investment		
System Investment	PPE	3010-Aircraft Procurement Aeronautical Vehicle Prior Year Credit Advance Buy Component Improvement Other Charges First Destination Trans.
Support Investment		
Support Equipment	PPE	3010-Aircraft Procurement Peculiar Support Common AGE (New Acquisition)
Training Equip & Services	PPE	Peculiar Support
Documentation	PPE	Peculiar Support
Initial Spares and Repair Parts	PPE	Weapon System Initial Spares Common AGE Spares Other Charges
Spare Engines	PPE	Weapon System Initial Spares
Facilities (Non-prod.)	PPE	3300-Military Construction 3400-Operations and Maintenance Other Purchased Services
War Reserve Material (WRM)		
Spares & Repair Parts	PPE	3010-Aircraft Procurement Weapon System Initial Spares Replenishment Spares (WRM)
Munitions	28030-WRM Ammunition	3080-Other Procurement Munitions & Assoc. Equipment
Missiles	27161-Tactical AIM Missiles 27162-Tactical AGM Missiles	3020-Missile Procurement
Tanks, Racks, Adaptors, and Pylons	PPE	3010-Aircraft Procurement War Consumables Other Charges
Operating and Support		
Deployed Unit Operations		
Aircrews	PPE (or CCT for same acft)	3500-Military Personnel AF Personnel-Officers AF Personnel-Airmen
Command Staff	" "	3500-Military Personnel AF Personnel-Officers AF Personnel-Airmen 3400-Operations and Maintenance Civilian Personnel Payments to FNIH Pers.
Aircraft POL	" "	3400-Operations and Maintenance Aircraft POL
Security	" "	3500-Military Personnel AF Personnel-Officers AF Personnel-Airmen
Other Deployed Manpower	" "	3500-Military Personnel AF Personnel-Officers AF Personnel-Airmen 3400-Operations and Maintenance Civilian Personnel Payments to FNIH Pers.
Miscellaneous O&M	" "	3400-Operations and Maintenance Travel of Personnel Transportation of Things Std. Level User Charges Utilities and Rents Communications Printing and Reproduction Purchased Equip Maint (Comm.) Purchased Equip Maint (other) Other Purchases from IF Other Purchased Services Other Supplies Equipment Other Expenses

Table 3 (continued)

Cost Category	F&FP Program Element	Appropriation/Cost Element
Below Depot Maintenance		
Aircraft Maint. Manpower	PPE (or CCT for same MDS)	3500-Military Personnel AF Personnel-Officers AF Personnel-Airmen 3400-Operations and Maintenance Civilian Personnel Payments to FNIH Pers.
Ordnance Maint. Manpower	" "	3500-Military Personnel AF Personnel-Officers AF Personnel-Airmen 3400-Operations and Maintenance Civilian Personnel Payments to FNIH Pers.
Maintenance Material	" "	3400-Operations and Maintenance Other Supplies Equipment
Miscellaneous O&M	" "	3400-Operations and Maintenance (see same category under Deployed Unit Operations)
Installations Support	xxx94-Real Property Maint. xxx95-Command & Base Comm. xxx96-Base Operations	3080-Other Procurement* 3300-Military Construction 3400-Operations and Maintenance* 3500-Military Personnel AF Personnel-Officers AF Personnel-Airmen
Depot Maintenance		
Manpower	72007-Depot Maint. (IF)	3400-Operations and Maintenance
Material	72207-Depot Maint. (non-IF)	Purchased Maintenance (DMIF) 3500-Military Personnel
Depot Supply		
Material Distribution	71111-Supply Depots/ Operations	3400-Operations and Maintenance Civilian Personnel
Material Management	71112-Inventory Control Point Operations 71113-Procurement Operations	3500-Military Personnel AF Personnel-Officers AF Personnel Airmen
Technical Support	71112-Inventory Control Point Operations	
Second Destination Trans.	78010-Second Destination Transportation	3400-Operations and Maintenance Transportation of Things
Pers. Training & Support		
Individual Training	81711-81714-Recruit Training 82727-ROTC 82728-Service Academy 82782-Specialized Training 82783-Professional Training 82784-Flight Training	3010-Aircraft Procurement* 3400-Operations and Maintenance* 3500-Military Personnel AF Personnel-Officers AF Personnel-Airmen AF Personnel-Cadets
Health Care	87711-Care in Defense Facil. 87713-Care in Non-Defense Facilities 87714-Other Health Activ.	3400-Operations and Maintenance* 3500-Military Personnel AF Personnel-Officers AF Personnel-Airmen
PCS Travel	88731-Permanent Change of Station	3500-Military Personnel PCS Travel
Sustaining Investments.		
Replenishment Spares	PPE (or CCT for same acft)	3010-Aircraft Procurement Replenishment Spares (costing)
Modifications	" "	Modifications Mod. Initial Spares
Replenishment Ground Support Equipment	" "	Common AGE (costing)
Training Ordnance		
Munitions	27599-Munitions Trng Items	3080-Other Procurement Munitions and Assoc. Equipment
Missiles	27161-Tactical AIM Missiles 27162-Tactical AGM Missiles	3020-Missile Procurement

* See Table A.2 for list of cost elements.

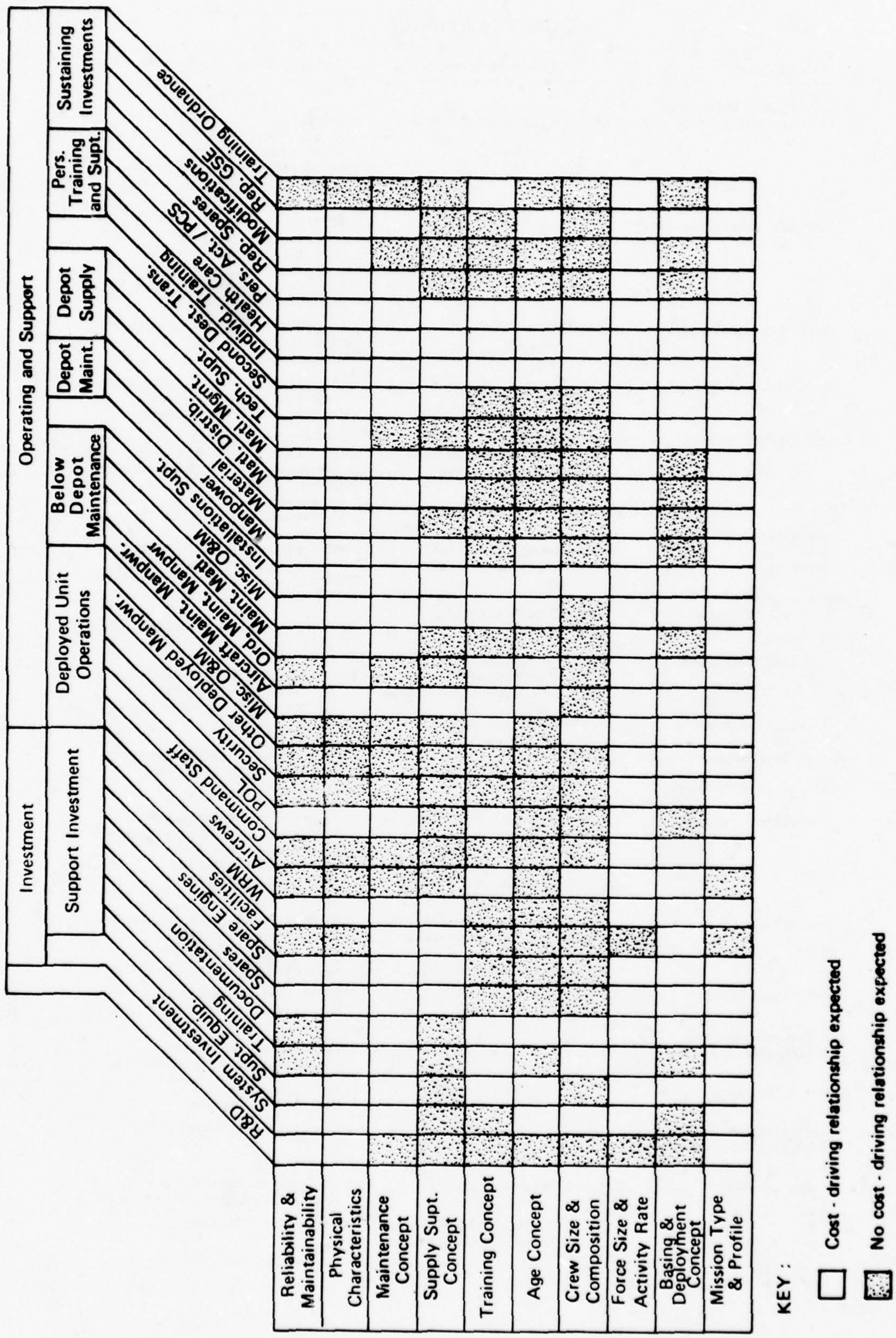

Fig. 1—Evaluation matrix

To evaluate each model, we examined the model's estimating methods and asked how well it could perform in estimating the effect on cost (within the cost elements the model was designed to cover) of a change in any of the driving factors. The judgment was a qualitative one, as quantitative measures of estimating ability at this level of generality are seldom feasible. For each relevant driving factor/cost element combination, we rated a model as providing: no coverage (i.e., the estimating method is incapable of reflecting any influence of the driving factor on the cost element), poor coverage, fair, or good. The context of this study required that the ratings be based on the model's ability to estimate *absolute* costs—not just relative costs. The ratings are displayed in the appropriate cells of the matrix using a color-coding scheme: shaded red for no coverage, solid red for poor coverage, yellow for fair, and green for good. Section III explains the basis for these ratings and assesses each model's estimating method. A full explanation of the ratings for each cell, for each model, is provided in Appendix B.

III. EVALUATION OF THE COST MODELS

This section discusses each cost model in terms of its overall structure, its estimating methodology, and the evaluation results. It provides an overview, for analysts and for system acquisition managers, of the estimating methodologies used in each of the generalized cost models, and an understanding of the strengths and weaknesses of the models. A narrative description of each model provides a general understanding of the type of estimating methodology used. An evaluation matrix shows specific strengths and weaknesses in the model's coverage of the LCC elements and of the driving factors. From the analyst's point of view, these evaluations indicate where a particular model's estimate should be backed up by supplementary analyses (possibly including the use of another model) or supporting data. From the decisionmaker's point of view, if the major cost effects of a proposal fall into categories where only fair or poor coverage is indicated for the model used to generate a cost estimate, then the outcome should be interpreted as "risky." That is, if no better information can be found to supplement the cost model, the decisionmaker should probably demand a larger payoff from the proposal than he would from a proposal for which firmer cost estimates were available.

This section also provides an overview of the "state of the art" in generalized models for life cycle cost estimating—the best capability that could be achieved through a combination of *all* of the evaluated models. An overview matrix is presented in which each cell is given the best rating among all the estimating techniques addressed. None of the models discussed here—nor any others that we know of—provides full coverage of the life cycle cost elements or of the major factors driving costs, which means that comprehensive cost estimates require a hybrid combination of generalized models or a combination of models and ad hoc methods.

EXPLANATION OF RATINGS

We made a careful examination of the cost estimating methods within the well-defined framework of the cost driving factor/cost element matrix to arrive at our evaluation. A *good coverage* rating (shown as green in an evaluation matrix) is clearly indicated when a model's estimating method closely follows the actual relationship between cost and driving factors (e.g., the BACE and CACE models' treatment of aircrew costs as a function of crew size and force size). The reason for a *no coverage* rating (red diagonals) is also usually clear. The reasons for and distinctions between fair and poor ratings are more complex. We assigned a *fair coverage* rating (yellow) where the cost driving relationship was only partially reflected in the estimating technique. For example, the investment cost of support equipment should be related to system reliability and maintainability characteristics, but most models simply relate support equipment cost to flyaway investment cost. Such an indirect connection probably fails to capture effects below the total aircraft system level. In some instances problems with cost data make it difficult or impossible to find the "true" cost of current systems (such as for indirect O&S

costs), and in such cases there is no way to measure the accuracy of a cost estimate objectively. With better information on current system costs we would have had a better basis for judgment, but without it we usually assigned *fair coverage* ratings if the estimating method seemed at least reasonable. A *poor coverage* rating (solid red) was assigned where a model dealt with only a minor portion of the expected cost effect, treated the relationship in a possibly misleading way, or had an unknown (or obscure) relationship to the content of the cost element as defined in Appendix A.[1] *Poor coverage* ratings were also assigned where the methodology was only remotely related to the driving factors. A *no coverage* rating was assigned where a model covers a cost element by using a "throughput" (externally calculated and merely displayed or added to other results by the model).

BACE AND CACE: USAF COST FACTORS MODELS

The *USAF Cost and Planning Factors* (AFR 173-10)[2] presents two models of aircraft squadron operating and support costs which broadly cover variable operating and support expenses and recurring investments. The Planning, Programming, and Budgeting Annual Cost Estimating (BACE) model is used to generate estimates for exercises conducted as part of the Planning, Programming, and Budgeting (PPB) system. The Cost Analysis Cost Estimating (CACE) model is used in "cost or research analyses, life cycle cost exercises, or studies concerned with cost effectiveness comparisons between weapon systems."[3] The regulation does not explain why two different models are needed or why PPB estimates should be conceptually different from estimates used in cost studies not directly related to PPB exercises. Most cost categories are estimated with the same methodology in both models.

The CACE model—or some close variant of it—is important in the life cycle analysis context and is frequently used by SPOs, contractors, and Air Staff offices to generate and/or display total system operating and support costs. It has also been suggested for use in developing O&S costs for reference systems and in setting O&S cost goals for new systems.

The BACE and CACE models calculate costs for a "typical aircraft squadron," using as the principal inputs: (1) unit equipment (UE) aircraft per squadron, (2) annual flying hours (FH) per aircraft, (3) manpower requirements per squadron, and (4) various cost factors, which are multiplied by the numbers of UE, FH, or men to generate the cost estimates. The cost factors and manpower inputs for most current systems (at current FH rates and squadron sizes) and for a few systems soon to enter the force are provided in the regulation. The regulation also provides a limited set of data and formulas that the analyst can use to change direct manpower inputs when UE and aircrew ratios (crews per UE) are changed and to change indirect manpower inputs when direct manpower changes. However, these manipulations must be performed outside the models.

The BACE model's estimates are compatible with official inputs to the develop-

[1] See the discussion in Appendix B of the BACE and CACE models' coverage of "miscellaneous O&M" costs, and the LSC model's coverage of training costs.

[2] Department of the Air Force, *USAF Cost and Planning Factors (U)*, AFR 173-10, February 6, 1975, with changes through May 2, 1977, Vol. I (For Official Use Only).

[3] Ibid., Vol. I, p. 2-15.

ment of the USAF Program Objective Memorandum (POM). However, a comparison of the "typical" squadron estimates with average PPE manpower and costs shown in the F&FP indicates that the models do not cover all the resources normally attributed to aircraft systems in the budget. Some of this discrepancy results from the exclusion of "fixed" costs, but some annually recurring costs apparently are excluded as well. The regulation indicates that the estimates are to be used in the "delta" mode—to estimate the incremental cost of adding or deleting a squadron, but not to establish a baseline. But when a system not yet in the force is being considered, a baseline (for that system) is essentially being established. Hence, an estimate for a new aircraft system based on BACE or CACE methodology and factors alone will probably not reflect the system's full marginal effect on USAF O&S resource requirements.

The factors in AFR 173-10 are generated by a number of different Air Staff and major command organizations—each using its own techniques.[4] Since these techniques are not documented in the regulation, the user cannot readily evaluate them or keep abreast of changes in them. The number of organizations involved introduces the possibility that incompatible definitions will be used for the factors for different elements. Another problem in some applications is that factors are provided only for existing, well-defined aircraft. To apply these models early in the development of a new aircraft requires the use of additional models or assumptions to generate appropriate cost factors and manpower estimates. Some of the factors (particularly those intended especially for BACE) are based on current budget-year requests, and hence they may reflect short-term peculiarities that are not applicable to the longer time horizon of life cycle analysis. Also, since the factors are only available at the total weapon system level, these models are not generally suitable for investigating changes at the subsystem level.

Cost outputs of the BACE and CACE models are limited in their sensitivity essentially to activity rate (FH), squadron size (UE), and manpower. However, even this sensitivity is limited, and the cost/FH and cost/UE factors may be inappropriate for activity rates or squadron sizes other than the FH and UE values for which the published factors were developed. The error should be small for small changes in FH or UE, but the user has no guide as to how far he can carry the published factors. The organizations that prepare the factors appear to recognize that some of the cost elements are not driven by the FH and UE levels alone, but the models themselves are not sensitive to other cost drivers. Meaningful manpower variations are even more of a problem, because no techniques are provided in the regulation for varying direct manpower inputs as functions of system characteristics or operations and support concepts.

The coverage of various LCC elements by BACE and CACE is summarized in Fig. 2. Neither model treats R&D or Initial Investment costs, or Depot Supply and Second Destination Transportation LCC categories. The LCC categories that are addressed by BACE and CACE are discussed individually in Appendix B. Sensitivity for aircrew costs is good, but for miscellaneous O&M cost elements it is poor. Sensitivity is fair to crew size and composition and to force size (the "squadron" costs can be multiplied outside the models by the number of squadrons in the force) and activity rate for most of the elements they cover. As an example, consider the

[4] For example, "Typical Squadron" manpower authorizations are provided by AF/PRM, depot maintenance cost factors by AFLC, training cost factors by ATC, etc.

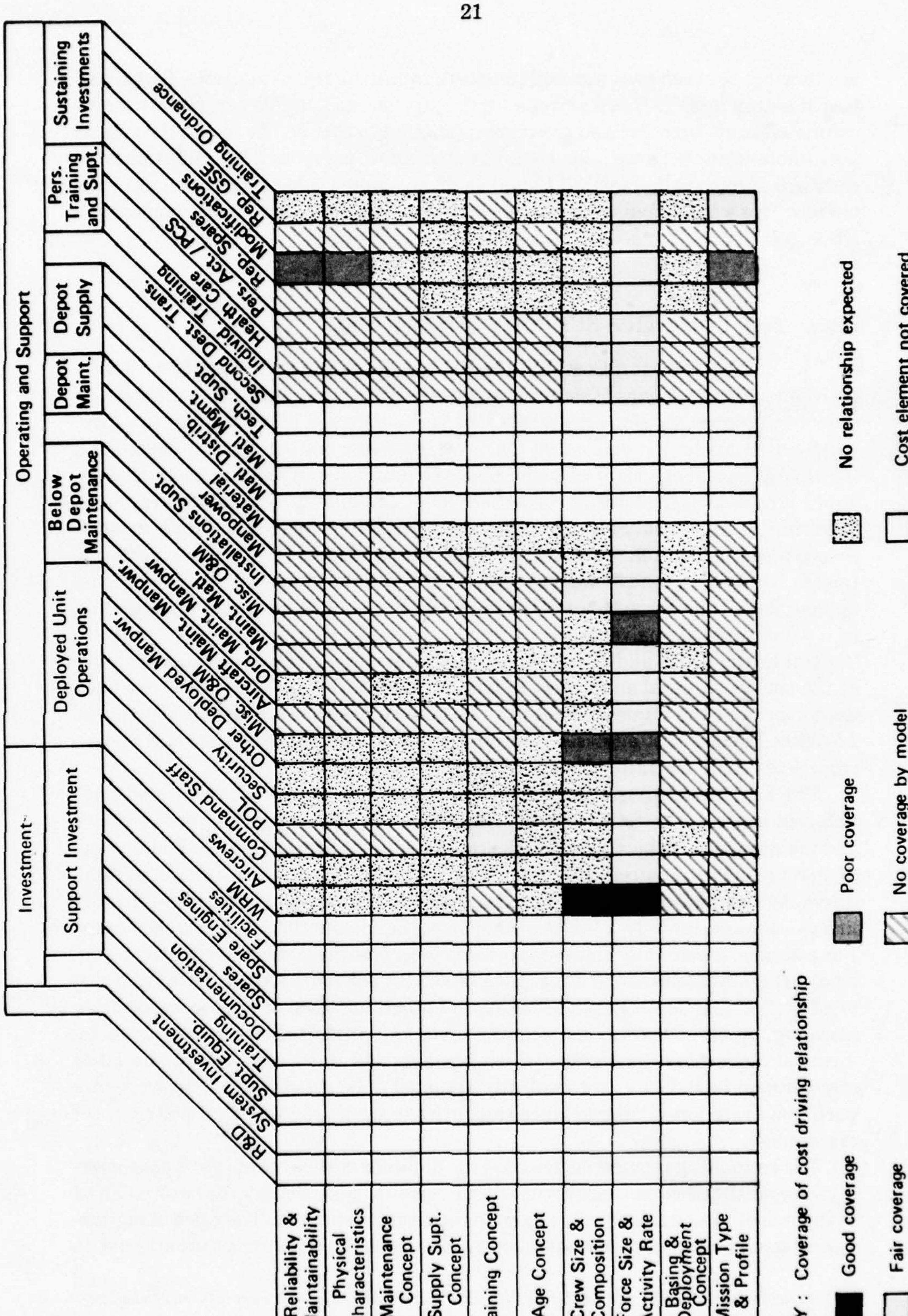

Fig. 2—Coverage of BACE and CACE models

relationship between crew size and composition and the cost of aircrews. BACE and CACE output total PPE manpower cost; the portion attributable to aircrews can be estimated from force size and crew size data input to CACE. The pay costs used do not differentiate between aircrew and non-aircrew personnel, but differentiated costs are published in AFR 173-10 and could be applied with slight changes to the models. This would produce estimates with good sensitivity to crew size and composition.

LSC: THE LOGISTICS SUPPORT COST MODEL

The Logistics Support Cost (LSC) model was developed by the Air Force Logistics Command as a means of estimating the difference between the support requirements of alternative aircraft designs.[5] In various forms, it is probably the most widely used model for generating O&S cost estimates during aircraft design.

LSC is typical of a class of model that uses cost equations to represent maintenance processes at the aircraft component level. Another model in this class, developed by The Analytical Sciences Corporation (TASC)[6] primarily for application to avionics equipment, offers somewhat different capabilities than LSC, which is intended to apply to entire weapon systems. Major portions of the TASC model appear to be valid for systems other than avionics, and it deserves consideration in a wide range of analyses.

Unlike the BACE and CACE models, LSC provides a great deal of cost visibility at the subsystem level and below. In part because of this visibility, LSC has been used to provide the framework for the "Targeted Logistics Effects" and "Measured Logistics Effects" cost analyses incorporated in the reliability improvement warranties for some aircraft systems (e.g., the F-16A).

The LSC model consists of ten equations that estimate cost associated with different aspects of logistics support. Most of the equations apply to maintenance and maintenance support. Some of the computed costs are actually only indicators of direct resource requirements, converted to dollars, rather than estimates of total, direct, incremental cost. This is because the simple estimating equations—usually linear—account for only a limited number of the factors that can influence costs. For example, to estimate maintenance manpower cost the model multiplies computed direct maintenance labor hours by a labor cost per man-hour, ignoring the cost of additional manpower required because of minimum team or shop sizes, position manning, or other operational requirements and organizational constraints. Indirect and overhead time costs, which are assumed to be captured in the labor cost-per-man-hour figure, are implicitly assumed to be generated at the same proportionate rate for all maintenance categories to which the standard hourly rates are applied.

The estimating methodologies used for different cost elements vary considerably in sophistication and sensitivity. Some costs are provided by the user as input to the model, which merely adds them to the costs it estimates. The costs of maintenance, spares, and support equipment are estimated by equations that attempt to

[5] Headquarters Air Force Acquisition Logistics Division (AFLC), *Logistics Support Cost Model User's Handbook*, August 1976.

[6] The Analytical Sciences Corporation, *Life-Cycle Cost Analysis Program Users Guide*, Report No. EM-2073-1, May 10, 1977.

relate support resource requirements to hardware R&M characteristics and to maintenance processes. R&M input is required down to the level of what is termed the first line unit (FLU). A FLU can be a line replaceable unit (LRU) in an avionics system or a non-avionics item that is treated the same as an LRU by the maintenance and supply organization. The maintenance cost computations are based on a reasonable and useful representation of standard repair practices, but the spares and support equipment equations have features that call for care in their use. The cost of spares is based on an expected backorder criterion that is applied to each FLU individually; there is no link between spares cost and overall supply effectiveness or aircraft availability. The support equipment equation computes the quantity of support equipment needed under the assumption that an item of support equipment must be available for use (unavailable to other users) for the full duration of each maintenance task that calls for the use of the equipment. In practice, support equipment requirements are strongly influenced by deployment plans, which are not considered in the model.

LSC's coverage of LCC elements as summarized in Fig. 3 is based on the individual cost element evaluations in Appendix B. The model does not address the following LCC elements: Research and Development, System Investment, War Reserve Material, Deployed Unit Operations (except for POL), Ordnance Maintenance Manpower, Miscellaneous O&M (for Below Depot Maintenance), Technical Support, Health Care, Personnel Support/PCS, Modifications, Replacement Ground Support Equipment, and Training Ordnance. LSC provides fair to good sensitivity to factors that drive Spare Engines costs. For most of the other cost elements it covers it provides fair sensitivity to reliability and maintainability, force size and activity rate, and basing and deployment concept. It provides either poor sensitivity or none at all to most other driving factors. The coverage of Aircraft Maintenance Manpower is typical. LSC is rated as providing fair coverage of the effects of physical characteristics on Aircraft Maintenance Manpower because it considers some but not all of the relevant causative agents. Physical characteristics are partially accounted for through the use of the number of engines and number of FLUs, but the model does not explicitly treat SRU repair. LSC provides generally poor coverage for Installations Support and for the training cost categories.

For most cost elements, an ultimate assessment of the model's sensitivity should consider a comparison of LSC estimates with actual *costs* incurred in the operational use of a system. We find no record of such a comparison having been attempted. The "Measured Logistics Effects" called for by some production contracts involve the measurement of reliability and maintainability data rather than costs.

LCOM: THE LOGISTICS COMPOSITE MODEL

The Logistics Composite (LCOM) model is a simulation model that represents the effects of base level support activities on aircraft flight operations. As originally developed,[7] it can handle a variety of different support resources such as manpow-

[7] Captain R. R. Fisher et al., *The Logistics Composite Model: An Overall View*, The Rand Corporation, RM-5544-PR, May 1968.

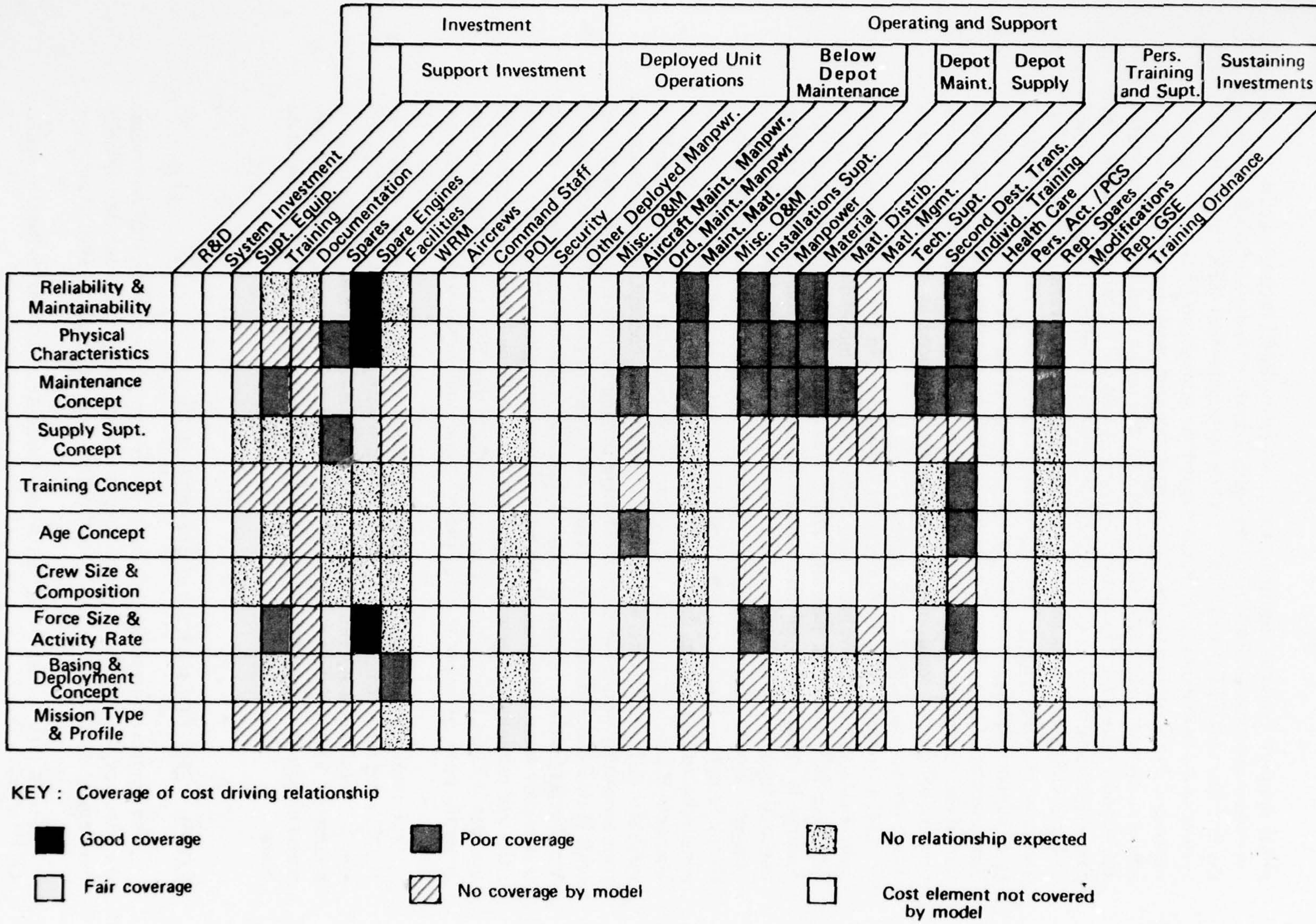

Fig. 3—Coverage of the LSC model

er, spares, and support equipment. The Air Force has used it most extensively in determining maintenance manpower requirements for new aircraft.[8] Additional computer programs have been developed for use with LCOM that translate new maintenance workload data into the form required by the simulation. They expand on the simulation results to produce a full manpower requirement, adding manpower categories that are not simulated and setting appropriate grade levels. Our evaluation examines the LCOM simulation itself in its role as an estimator of manpower. Manpower requirements established by forcewide standards are considered separately later in this section.

Because of the richness of its input data, LCOM is usually used only after the onset of full scale development, and then only by an Air Force team. It is not normally included in the category of life cycle cost models, but its ability to deal with the nonlinearities in maintenance manpower requirements is important. LCOM is included here for that reason and because its manpower requirements computation may be used in LCC studies.

Its output is the number of personnel needed in each modeled work center. LCOM is usually applied only to work centers that contribute directly to sortie generation because it can account for the impact of resource quantities on an organization's ability to generate sorties. It is mainly this feature that justifies the use of such a complex model.

LCOM requires a substantial amount of input data. The user must define a set of task networks that identify each task or process associated with flying a mission, servicing aircraft, or performing corrective maintenance. Each task's resource requirements must be specified, including the time required to complete the task, along with inputs that determine when (under what conditions or at what times) the task will be performed. Hardware R&M data are specified at a level of detail corresponding to the maintenance task definitions. This input is typically provided at the three-digit work unit code level.

Because detailed task networks are used, the model is sensitive to changes in the maintenance processes as well as to changes in R&M. The model's structure is oriented toward the organizational structure and policies defined in AFM 66-1[9]; in its present form the model cannot handle all resource substitutions that would occur under some new maintenance concepts, such as the Production-Oriented Maintenance Organization (POMO) developed in the Tactical Air Command. This limitation may not be serious; the model changes needed to provide a capability to address all aspects of such new concepts could probably be implemented easily.

LCOM is most often used to compute requirements for the LCC elements Aircraft Maintenance Manpower and Ordnance Maintenance Manpower. Even in these categories, LCOM has not been applied to all the relevant work centers. Table 4 lists the aircraft maintenance work centers to which LCOM has been applied (for some current fighter aircraft), and those to which it has not been applied. An examination of the manpower required in the individual work centers has shown that the centers covered by LCOM have accounted for only 40 to 50 percent of total aircraft maintenance manpower.

[8] Major Donald C. Tetmeyer and SMSgt William D. Moody, *Simulating Maintenance Manning for New Weapon Systems: Building and Operating a Simulation Model*, AFSC, AFHRL-TR-74-97 (II), December 1974.

[9] Department of the Air Force, *Maintenance Management*, AFM 66-1, May 1, 1974.

Table 4

LCOM COVERAGE OF AIRCRAFT MAINTENANCE WORK CENTERS

Work Center	LCOM-Manned Aircraft					
	F-4E	A-7D	RF-4C	F-111D	F-16	None
Chief of Maintenance						x
Organizational Maintenance						
Overhead & Supervision						x
Flight Line	x	x	x	x	x	
Inspection	x	x	x	x	x	
Support Equipment						x
Field Maintenance						
Overhead & Supervision						x
Machine Shop	x	x	x			
Metal Processing	x	x	x			
Structural Repair	x	x	x	x	x	
Corrosion Control						x
Survival Equipment						x
Nondestructive Inspection						x
Jet Engine	x	x	x	x	x	
Repair & Reclamation						x
Fuel Systems	x	x	x	x	x	
Electrical Systems	x	x	x	x	x	
Pneudraulics	x	x	x	x	x	
Environmental Systems	x	x	x	x	x	
Egress Systems	x	x	x	x	x	
Aerospace Ground Equip. Management						x
AGE Repair & Inspection						x
AGE Service, Pickup, & Delivery						x
Avionics Maintenance						
Overhead & Supervision						x
Radio	x	x	x			
Radar	x	x	x			
Inertial Navigation	x	x	x			
ECM Pods						x
Automatic Flight Control	x	x	x		x	
Instruments	x	x	x		x	
Flight Line Avionics				x		
Integrated System Fire Control	x	x				
Photographic Sensors	x	x	x			
Communication-Navigation-Penetration Aids					x	
Weapons Control-Inertial Navigation					x	
Automatic Test Stations				x	x	
Manual Test Stations				x		
Avionics AGE					x	

The coverage of LCOM is summarized in Fig. 4. For those manpower categories it addresses, LCOM provides fairly good sensitivity to most of the factors that drive maintenance manpower, although its inability to address some maintenance functions means that its sensitivity can only be rated fair. LCOM can, for instance, readily estimate the effects of force size and activity rate on functions it addresses because these are basic elements of the operating scenario that is needed to apply the model. LCOM does not address training concept, and its capability to deal with changes in maintenance concept is limited.

MOD-METRIC: A MULTI-ITEM, MULTI-ECHELON, MULTI-INDENTURE INVENTORY MODEL

Although recoverable spares requirements (inventory) are treated to some extent by the LSC model, more detailed analyses of such requirements are often conducted for new aircraft systems using MOD-METRIC.[10] This model is an extension of a Rand model[11] developed to assist in the management of recoverable items in a multi-item, multi-echelon system. MOD-METRIC adds the feature of allowing for multiple hardware indentures (e.g., SRU items within LRU items) which makes the model useful for computing requirements for modular engines as well as for other aircraft components.

MOD-METRIC, originally developed for logistics use, has been adopted for use in life cycle cost studies. The model—or a simplified version of it—can sometimes replace the less sophisticated spares equations usually found in models (such as LSC) constructed to address a wider range of cost elements. Such a merger of models combines the validity and sensitivity of the MOD-METRIC approach with the broader cost coverage of the cost model.

The approach used in MOD-METRIC is also used in a Logistics Management Institute model[12] developed to examine spares availability across weapon systems. This model, which optimizes the cost-effectiveness of the spares that can be added to the inventory with procurement funds, is suitable for application to Air Force replenishment spares budgeting.

MOD-METRIC relates total investment in an inventory of various recoverable items to overall supply effectiveness, represented by total expected base-level backorders. The methodology is based on the concept of marginal analysis: funds are allocated to those items that will give the greatest backorder reduction per dollar. The mathematical analysis that implements the concept is more sophisticated than the analyses supporting the other models discussed here. The algorithms represent logical supply processes, but not those used by the Air Force. The current AFLC computer program for MOD-METRIC adds to the depot inventory a quantity of spares sufficient to offset inventory reductions due to condemnations during the time required to replace the condemned items. This is a supplement to the basic inventory computations and not an estimate of the cost of replenishment spares.

[10] Air Force Logistics Command, *Recoverable Inventory Control Using MOD-METRIC*, AFLCP 57-13, February 28, 1975.

[11] Craig G. Sherbrooke, *METRIC: A Multi-Echelon Technique for Recoverable Item Control*, The Rand Corporation, RM-5078-PR, November 1966.

[12] Logistics Management Institute, *Measurements of Military Essentiality*, Task 72-3, August 1972; *A Model to Allocate Repair Dollars and Facilities Optimally*, Task 74-9, August 1974.

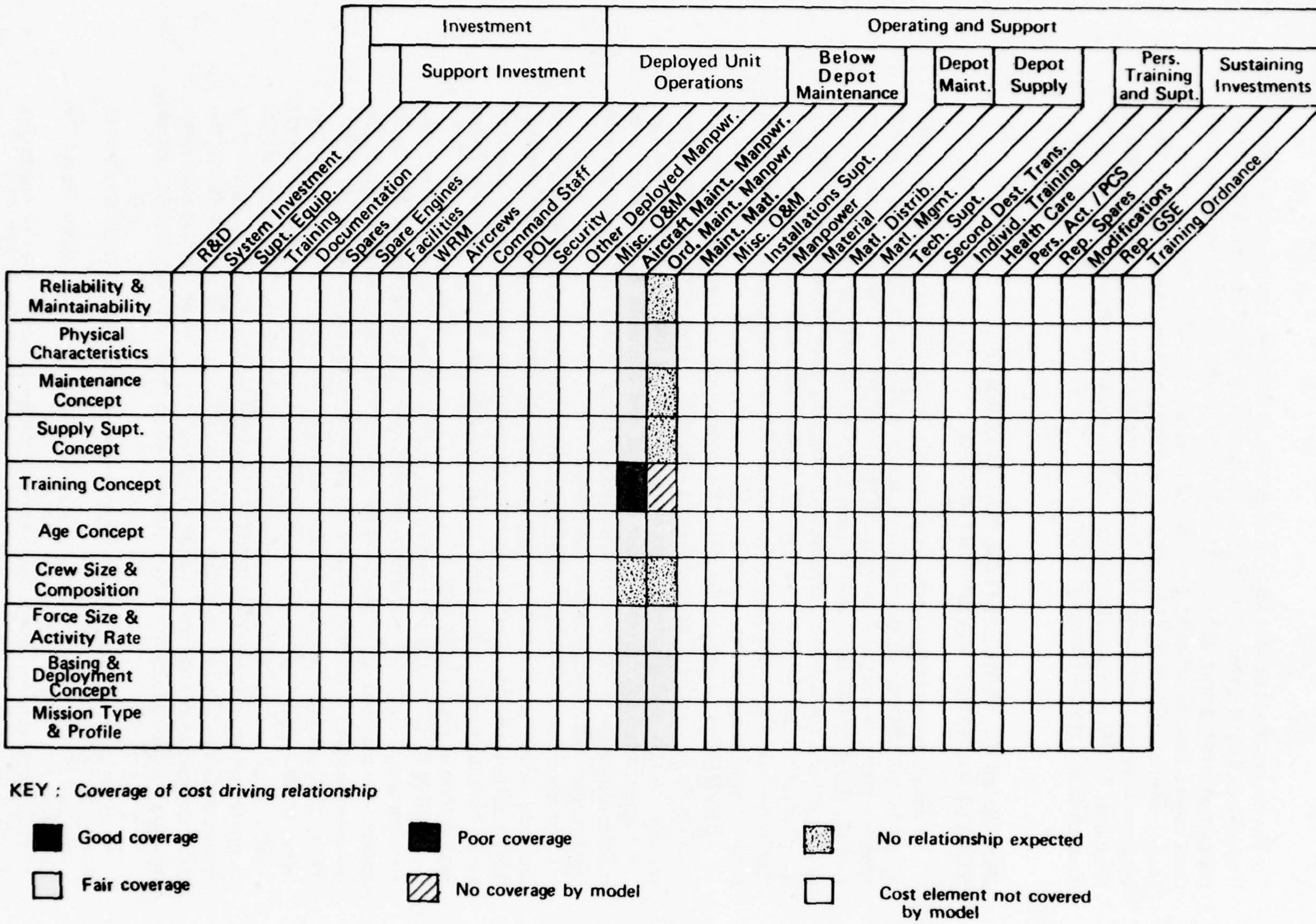

Fig. 4—Coverage of LCOM

MOD-METRIC inventory computations relate to three LCC elements: Initial Spares and Repair Parts, Spare Engines, and War Readiness Material. These are given in Fig. 5; Appendix B documents the reasons that led to the ratings shown. For Initial Spares and Repair Parts, for example, the model is credited with sensitivity to R&M characteristics because it uses item demand rates, NRTS rates, and repair cycle times, which are related to item failure rates (reliability) and ease of repair (maintainability). This capability is rated only fair because (1) item demands are expressed in terms of theoretical distributions involving parameters that cannot always be derived from Air Force historical information and (2) NRTS rates and repair cycle times are influenced by many factors other than hardware maintainability (e.g., availability of skills and tools, total workload), so the model has no capability for direct manipulation of maintainability.

AIR FORCE MANPOWER STANDARDS

The *Air Force Manpower Standards* manual, AFM 26-3, contains standards approved by Hq USAF that are used in establishing detailed manpower authorizations.[13] These standards are for use by more than one major command. Added or alternative standards developed by the commands and approved by Hq USAF are published in command manpower regulations. Manpower standards are defined at the work center level, and the parameters or driving factors (workload factors) that are used vary from one work center to another.

These standards are the working tools that the Directorate of Manpower and Organization (at Hq USAF and major command headquarters) uses to establish manpower authorizations for all work centers except ones where standards have not been developed. In that sense they are perfect predictors of manpower requirements, but in practice the standards are not readily applied to life cycle analysis problems because (1) the published standards (in AFM 26-3) fail to cover some important work centers; (2) the workload factors for some standards are not available during the development and procurement phases of an aircraft system's life (e.g., number of base supply system line items); (3) some standards are system peculiar, and new standards would be required for new systems; and (4) the standards are not sensitive to some of the driving factors needed for LCC applications. For a few work centers, however, the standards provide greater sensitivity than is available in other models.

Although we have examined some command-level standards (for Tactical Air Command), we have not evaluated them in detail. They help to fill some but not all of the gaps in coverage in AFM 26-3, but they are not as readily available to cost analysts, and they are also difficult to apply before a system is fully operational.

The evaluation of AFM 26-3 standards is summarized in Fig. 6 for the LCC categories they address: Command Staff, Other Deployed Manpower, Aircraft Maintenance Manpower, and Ordnance Maintenance Manpower. The cost elements are discussed fully in Appendix B. The standards relevant to Ordnance Maintenance Manpower are typical. They provide useful but limited sensitivity to force size and activity rate and to mission type and profile: AFM 26-3 has standards

[13] Department of the Air Force, *Air Force Manpower Standards*, AFM 26-3, February 27, 1973.

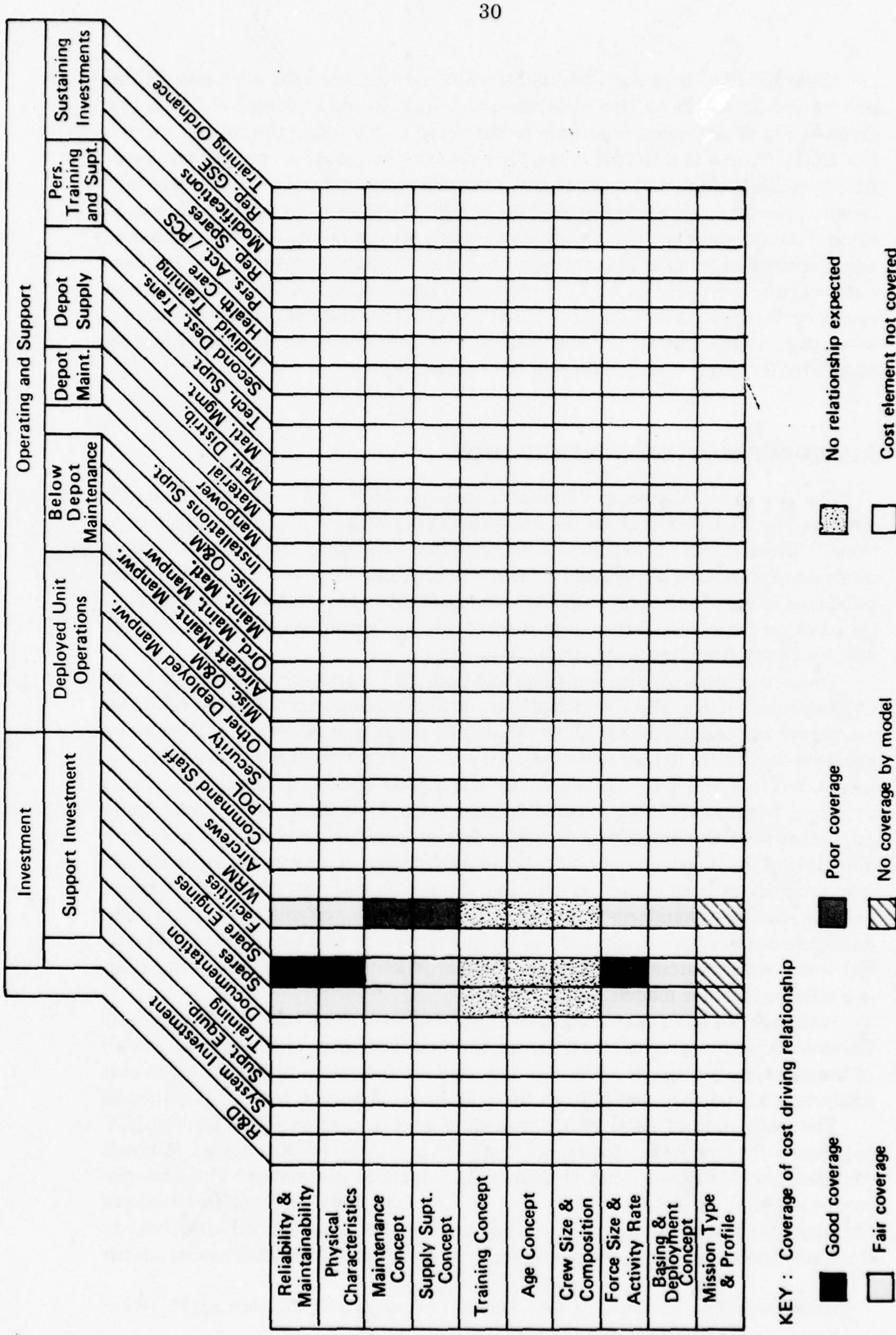

Fig. 5—Coverage of MOD-METRIC

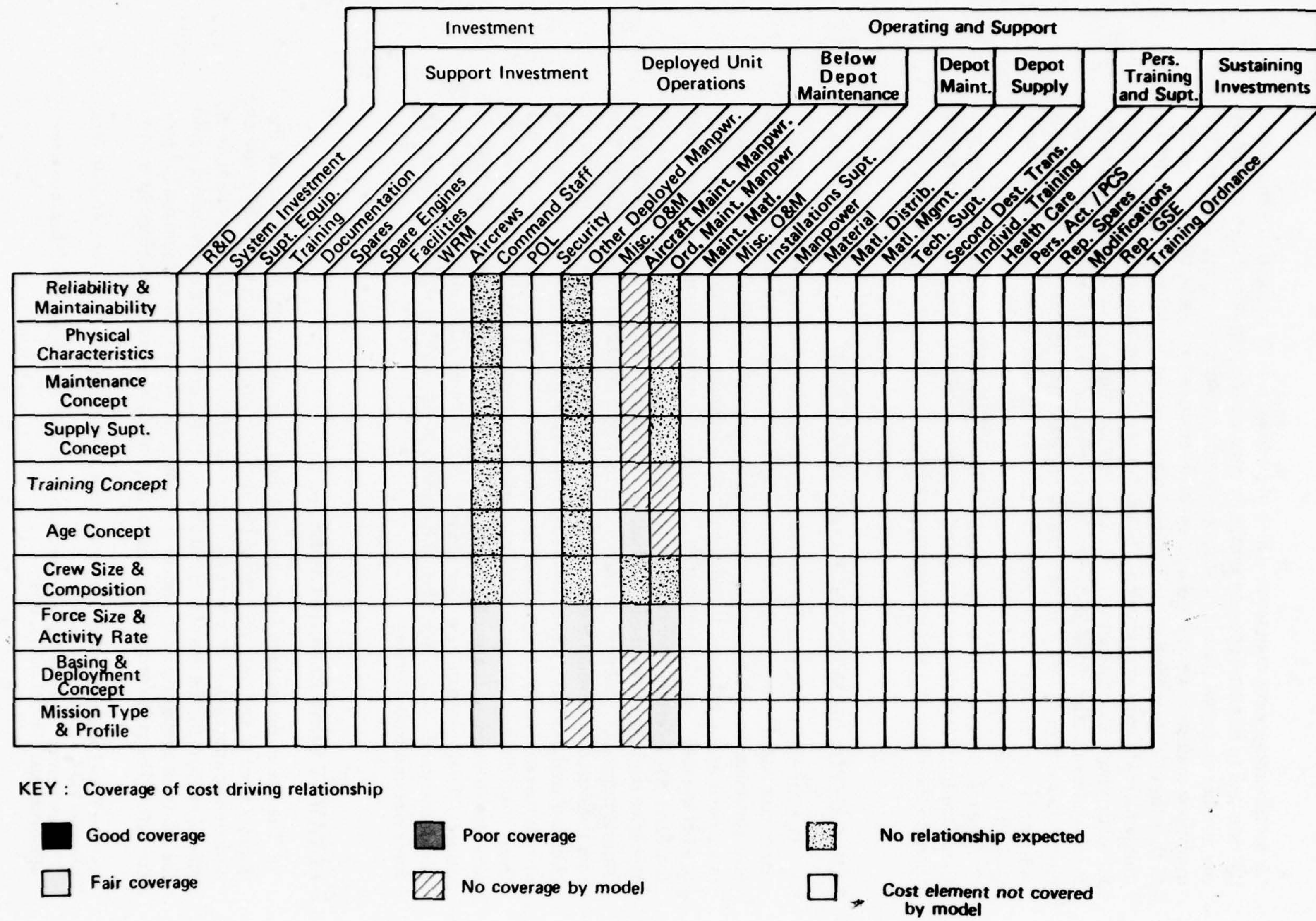

Fig. 6—Coverage of AFM 26-3 manpower standards

for munitions services manpower which provide sensitivity to force size and activity rate and to mission type and profile by relating the number of men needed to the number and type of aircraft supported and to their mission; the standards for munitions maintenance and storage are also sensitive to mission type and profile in that they relate manpower to the total weight of the munitions assigned to the unit, which will vary with mission. The usefulness of these standards is constrained for all driving factor categories by the lack of a technique for developing standards for new aircraft. Also, AFM 26-3 provides no standards for some manpower categories included in ordnance maintenance. Because of these limitations, the AFM 26-3 standards provide only fair coverage for this cost element. Coverage of other costs is similarly limited.

The manual also contains standards for Installations Support work centers, but these are for total base manpower and would require extensive analysis to relate them to the effect of a single weapon system on Installations Support manpower.

AFLC DEPOT MAINTENANCE COST EQUATIONS

The Air Force Logistics Command has developed equations for depot maintenance cost based on aircraft physical and performance characteristics.[14] The result of a statistical analysis of depot maintenance cost data using physical characteristics such as weight, speed, and thrust as independent variables, the equations predict the total cost of maintenance. For organic maintenance this includes labor, material, and overhead; for contract maintenance, the cost of the contract and the cost of government furnished material. The equations therefore apply to the Depot Maintenance LCC category as shown in Fig. 7 and discussed in Appendix B. The cost data used to develop the equations were derived in part by allocating engine overhaul and accessory repair costs to aircraft by MDS. These allocation processes are sources of error that cannot be avoided, since available depot data do not relate these costs directly to mission/design/series. The pamphlet does not describe any attempt to validate the equations, so their ability to make useful predictions is suspect. They estimate cost per aircraft, and a linear relationship between cost and force size is reasonable; thus the equations are credited with fair coverage of force size and activity rate.

FLYAWAY COST PERCENTAGES

The use of percentage factors (multiplied by flyaway cost) is a technique frequently used to estimate the cost of logistics investments. It deserves mention as a modeling approach if only because of its widespread acceptance. One example of official support for the use of such factors is an Air Force Logistics Command guide for analysts preparing estimates of the cost of logistic support resources for new aircraft.[15] The guide proposes the use of flyaway cost percentage factors for modifi-

[14] Air Force Logistics Command, *Estimating Depot Maintenance Costs for Air Force Aircraft*, AFLC Pamphlet 173-4, June 22, 1973.

[15] Headquarters Air Force Logistics Command, *A Guide for Estimating Aircraft Logistics Support*, AFLC Pamphlet 173-3, March 12, 1974.

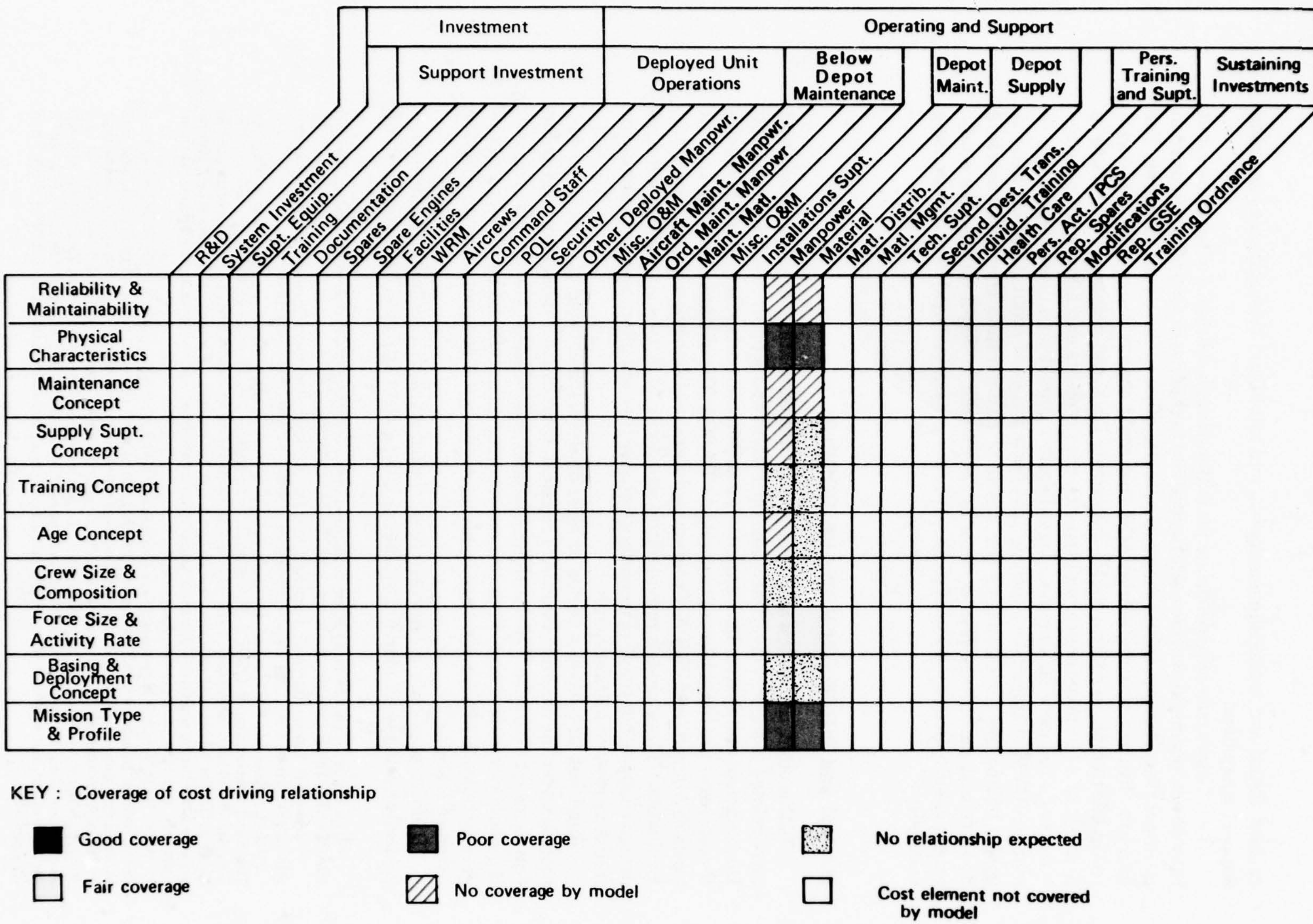

Fig. 7—Coverage of AFLC depot maintenance cost equations

cations, initial and replenishment spares, and initial and replenishment common support equipment.

Such factors may be appropriate for making rough estimates of total costs, but they do not in general provide useful sensitivity to changes in aircraft configuration or in policies. The cost effects they estimate are often in the wrong direction. For example, flyaway cost and initial AGE cost could change in opposite ways as a result of attempts to control R&M—improving R&M can require paying more in flyaway cost but may reduce maintenance requirements and allow AGE procurement to be reduced. This methodology therefore provides no useful sensitivity to manage R&M changes. We conclude that percentages of acquisition cost are not useful techniques for estimating the effects of configuration changes. Therefore flyaway cost percentage factors were not evaluated in detail during this study, except as such factors were used explicitly in the generalized models and estimating methods.

DAPCA and PRICE: HARDWARE MODELS

To this point, the models and other generalized estimating techniques discussed have related to support investment and operations and support costs. Research and Development and System Investment—the acquisition costs of the aircraft vehicles themselves—are the subject of two models: DAPCA (Development And Production Costs of Aircraft) and PRICE (Programmed Review of Information for Costing and Evaluation). These models provide little sensitivity to factors involved in detailed design changes, but they are important because they are often used as the basis for initial hardware cost estimates.

Rand has developed a series of aircraft development and procurement cost models under the acronym DAPCA. The latest, DAPCA-III,[16] is based on regression equations for airframes[17] and turbine engines[18] published previously. The estimating equations were drawn from cost experience on aircraft and turbine engines of several types. DAPCA's coverage is incomplete in that it does not estimate costs for avionics systems.[19]

DAPCA uses only a few variables, consistent with the limited information typically available for planning studies or independent analyses. Its coverage of the

[16] H. E. Boren, Jr., *A Computer Model for Estimating Development and Procurement Costs of Aircraft (DAPCA-III)*, The Rand Corporation, R-1854-PR, March 1976.

[17] Joseph P. Large, Harry G. Campbell, and David Cates, *Parametric Equations for Estimating Aircraft Airframe Costs*, The Rand Corporation, R-1693-1-PA&E, February 1976.

[18] J. R. Nelson and F. S. Timson, *Relating Technology to Acquisition Costs: Aircraft Turbine Engines*, The Rand Corporation, R-1288-PR, March 1974; J. R. Nelson, *Life-Cycle Analysis of Aircraft Turbine Engines*, R-2103-AF, September 1977. The equations in the latter report are not fully incorporated in DAPCA-III; the report also provides new methodology for estimating engine O&S costs which should provide some useful sensitivity (for those costs) to new variables—including technology level, overhaul intervals, and time in operational service.

[19] The DAPCA model is discussed here because of its widespread use in the Air Force and elsewhere in the defense community and because of the range of aircraft types represented in its data base and estimating equations. Other aircraft cost models of more limited scope but of essentially the same type as DAPCA include: M. N. Beltramo et al., *Parametric Study of Transport Aircraft Systems Cost and Weight*, Science Applications, Inc., April 1977; R. A. Groemping and J. W. Noah, *Estimating Aircraft Acquisition Costs by Parametric Methods*, J. Watson Noah Associates, Inc., TR-10618-USN, May 1977; *Methods of Estimating Fixed-Wing Airframe Costs*, Planning Research Corporation, R-547A, Vols. I and II, April 1967.

effects of physical characteristics is rated fair because it is sensitive to some causative agents but omits others. Weight, speed, and engine thrust are major input variables for DAPCA; these provide some implicit sensitivity to structural material and complexity. DAPCA does not address commonality. Driving factor sensitivity for each cost element is discussed fully in Appendix B and summarized in Fig. 8.

RCA has developed a technique called Programmed Review of Information for Costing and Evaluation (PRICE) for estimating development and production costs of systems with electronic and mechanical components. The model incorporates a data base from which it generates appropriate cost estimating relationships for each application.[20] This is a proprietary model, and its use must be purchased from RCA. Since it cannot be used directly by organizations other than RCA, it is not readily available in the sense that the other models are. It is included in this evaluation because it is popular and because none of the other models addresses the development and production of avionics systems. In the absence of detailed information on the PRICE algorithms, they have been assumed to give fair coverage of all driving factors they address. This is illustrated in Fig. 9. More detailed information is included in Appendix B.

OVERVIEW OF COMBINED MODELS

The evaluation matrix in Fig. 10 summarizes the overall assessment of the models. The color coding is the same as that used in the individual model evaluation charts: black shading indicates combinations for which no relationship is expected. A red-shaded block indicates that none of the cost models examined deals with the driving-factor/cost-element combination that the block represents. A solid red, yellow, or green block indicates the best capability among all the models that address the combination. Solid red is used where the best model deals with a relationship in a way that is possibly misleading or that has an unknown or obscure connection with the content of the cost element. A yellow block indicates that at least one model provides limited sensitivity to the expected cause-effect relationship. If one or more models represent the full extent of the relationship between a driving factor and a cost element, the corresponding block is green.

It is clear from the overall picture in Fig. 10 that not many of the expected cause-effect relationships between the cost driving factors and the cost elements are well covered by the generalized models and estimating techniques examined in this study. For blocks colored red (solid or shaded), the models provide essentially no useful capability for the evaluation of proposed weapon system program changes. For those shaded yellow, the models provide some capability; but they have deficiencies that analysts should consider when producing and presenting the results of an analysis. In any specific life cycle analysis problem, some cells are more important than others because they account for a greater proportion of the proposal's cost effect. If the matrix indicates that the commonly used techniques fail to deal adequately with one of the more important cells, then it may be possible to generate an engineering estimate (usually for investment items only) or to do a detailed analysis of historical cost data in order to find a suitable estimating relationship.

[20] RCA Government and Commercial Systems, *PRICE Reference Material*, October 1976.

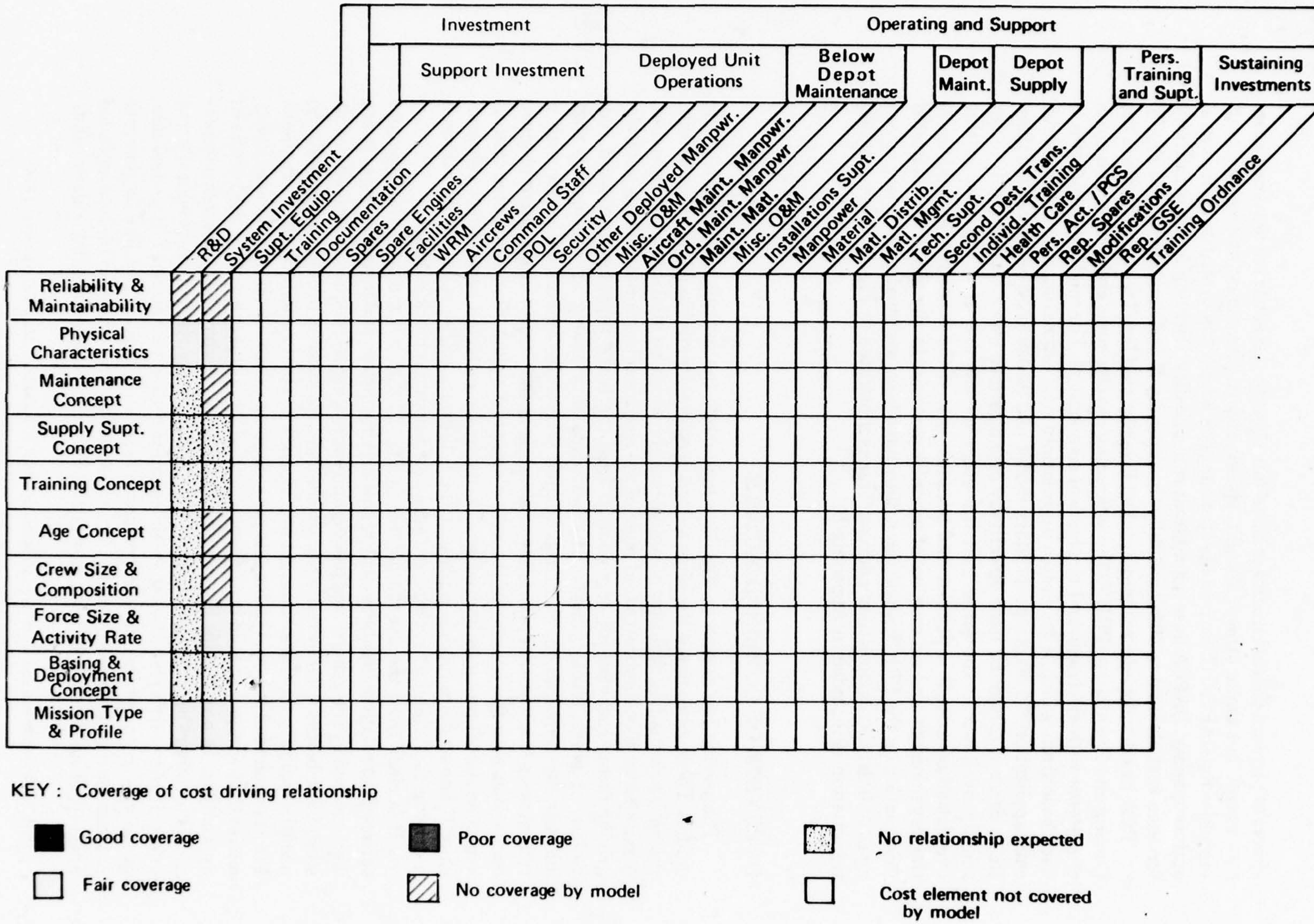

Fig. 8—Coverage of the DAPCA model

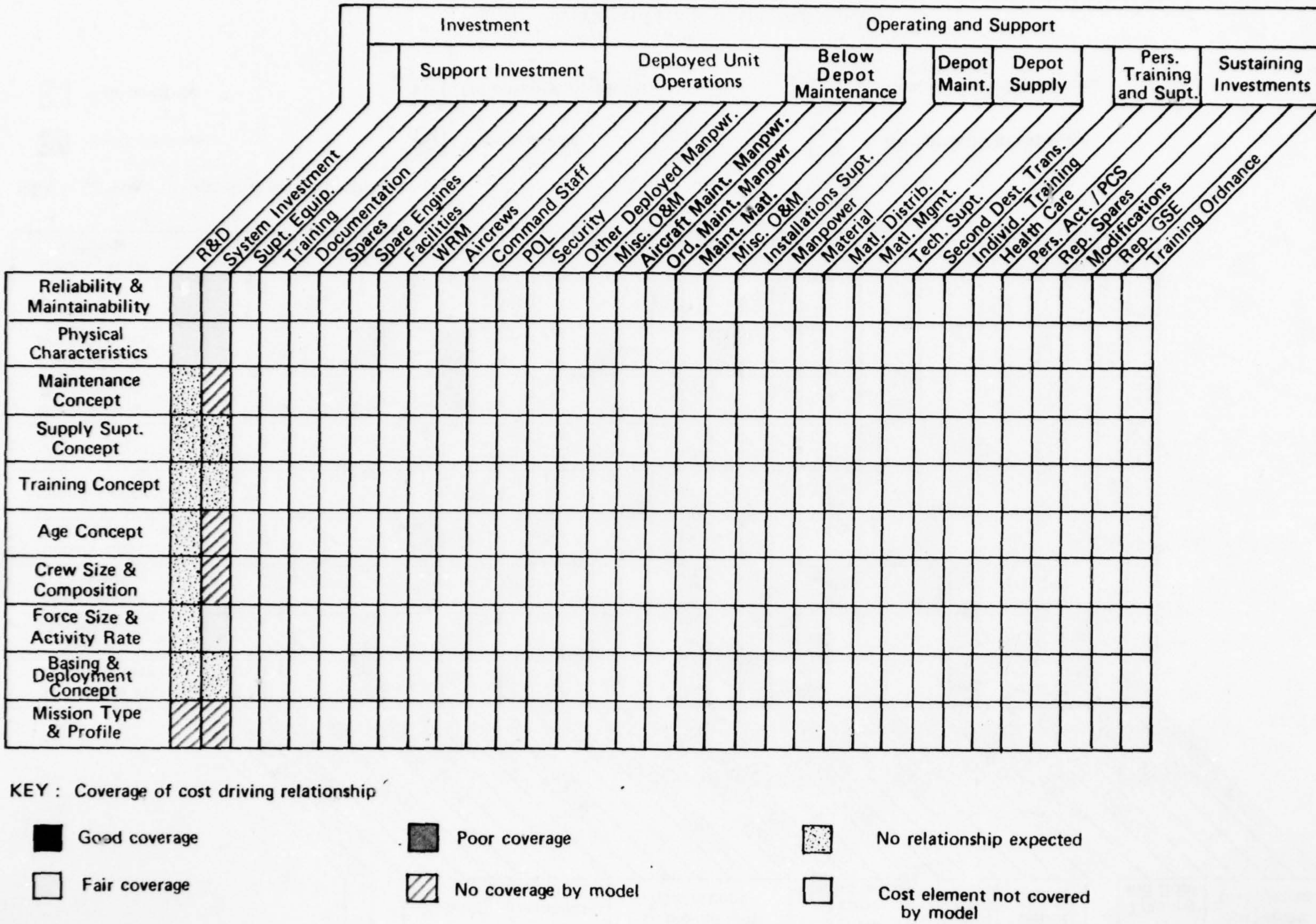

Fig. 9—Coverage of the PRICE model

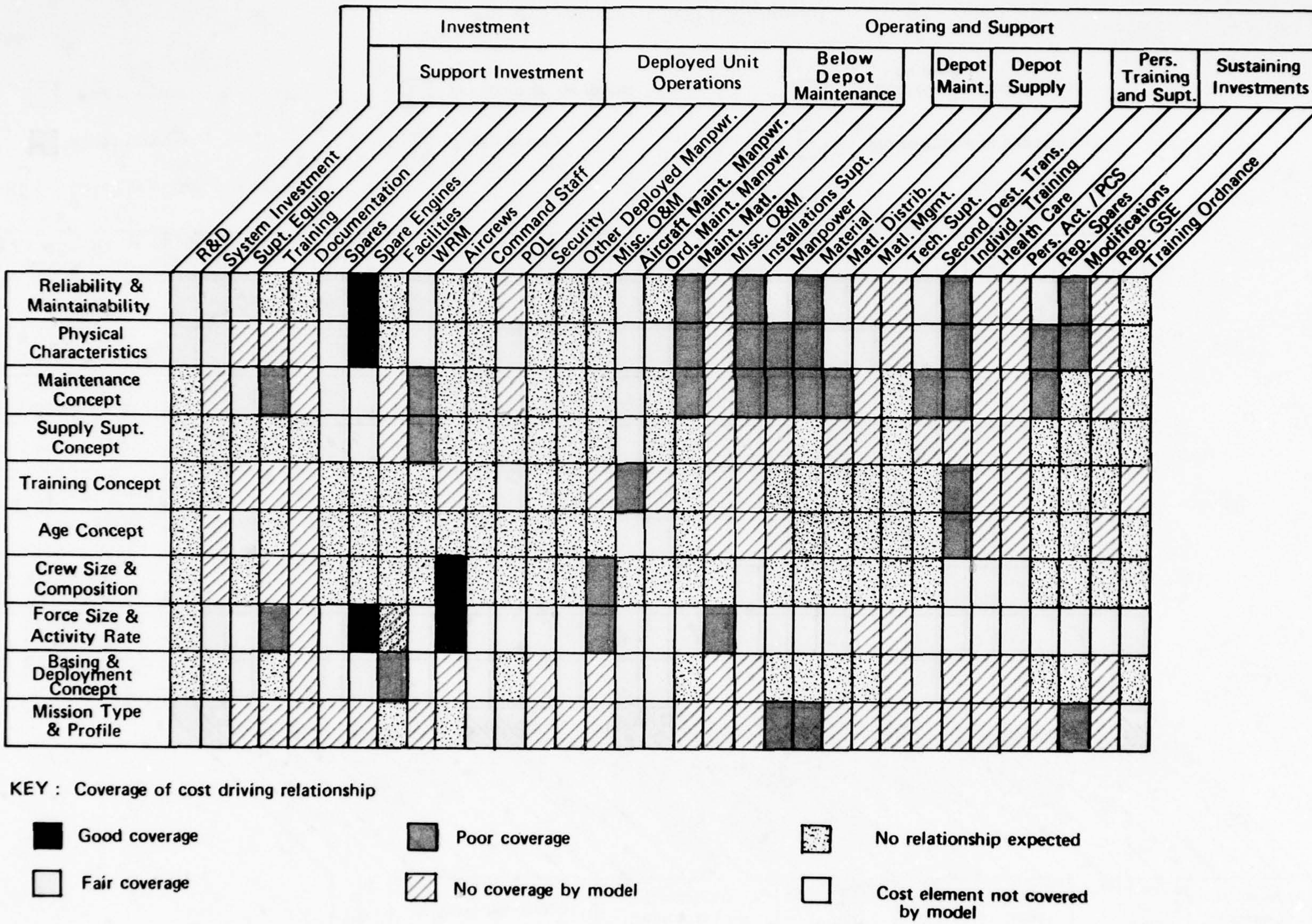

Fig. 10—Overall coverage of the cost models

When special studies or data collection efforts cannot overcome the deficiencies of the models, it is important that the analyst inform the decisionmaker that the estimates may not justify a choice among the alternatives solely on the basis of cost. These deficiencies would be appropriate subjects for future cost analysis research—research directed toward collecting data on driving factors and costs and identifying real-world, cause-effect relationships.

It may not always be practical to use the models in combination (e.g., time constraints in a study may not permit the use of a model such as LCOM); hence, it may be difficult to achieve in practice the collective best capabilities of the models. Nevertheless, it is enlightening to consider the best that could be achieved with these models if current practical constraints were eliminated. Besides providing analysts and decisionmakers with a general understanding of what can be achieved with available LCC models, these overall results highlight areas in which additional research is needed to support the development of improved models.

IV. CONCLUSIONS

OVERVIEW OF THE EVALUATION RESULTS

The cost models reviewed in this study differ substantially in their intended use, coverage of cost elements, and the strengths and weaknesses of their estimating techniques. The individual model evaluations and the summary evaluation in Sec. III indicate that the models can produce reliable estimates of the total incremental and absolute cost of a proposal in only a few areas and that they provide no useful cost estimating capability in many areas. More than 60 percent of the relevant driving factor/cost element cells in the overall evaluation matrix are either not covered by the models or are rated as having poor coverage; only 2 percent receive a good coverage rating. The relative importance of each driving factor/cost element combination will vary from one life cycle analysis study to the next, but clearly, the models cannot in most cases serve as a firm basis for life cycle cost estimates without additional supporting data and analyses.

The criterion for judging the models' estimating capability—i.e., their ability to estimate the absolute, incremental costs of a proposal—is stricter than usually thought necessary for many applications of life cycle analysis. However, in applications involving funding decisions or economic tradeoffs (acquisition cost versus O&S cost), this strict interpretation seems warranted. Although for the most part the LCC models were not originally intended for the level of detail and precision that is needed in estimating absolute, incremental costs, they are now used extensively in analyses calling for such cost estimates. Hence their capabilities should be evaluated with this in mind.

In many decisions supported by an LCC estimate, the acquisition cost estimates and O&S cost estimates differ fundamentally in meaning. R&D and system investment cost estimates are often based on fairly specific information (sometimes on a contractor's quote) and tend to represent hard, measurable dollars. Estimates of O&S costs (which virtually always come from models) tend to be "figures of merit" rather than predictions of dollar costs that can be observed and verified in the future. These figures of merit may be adequate for comparing alternatives having similar acquisition costs, provided the O&S costs of all alternatives are similarly distributed among the various O&S cost elements. Often, however, this is not the case. Typically, the relative costs of manpower, spare parts, POL, and other O&S resources required will differ from one alternative to another because of differences in design or in O&S concepts. In such instances, figures of merit are not sufficient; only absolute O&S cost totals can capture the actual differences between alternatives. Furthermore, when the primary justification of a proposed change is an economic one—i.e., the O&S costs savings that accrue over time are said to exceed the acquisition costs—the O&S cost estimates must be comparable with the estimates of near term R&D and procurement costs. In short, although a figure-of-merit estimate may, under certain circumstances, show that one alternative will probably have a lower O&S cost than another, it is almost always a poor basis for concluding that incremental savings are worth any preceding incremental investment.

The principal message that emerges from our research is that current LCC

models contain many shortcomings that limit their usefulness for life cycle analyses of major modification proposals or other applications requiring estimates of absolute incremental cost. When the evaluations indicate that a proposal's principal cost driving factors and cost elements are addressed poorly (or not at all) the models should be used cautiously, and any cost savings predicted should be strongly supported by additional analysis or empirical evidence. In such cases the analyst would be well advised to seek another, more reliable means of estimation if one is available; if none is available he should clearly identify the limitations and degree of uncertainty attached to the estimate, suggesting ways to improve the basis for the cost estimate—by new data collection efforts or test programs, for example.

FUTURE IMPROVEMENTS IN LCC MODELS

Despite this bleak picture, the framework used here suggests some major areas of research for long term improvements and some steps that can lead to improved analysis results in the short term.

Long Term Improvements

The major improvement needed in LCC models is a more realistic representation of costs from two aspects: (1) The full range of LCC elements needs uniform coverage in terms that relate to Air Force programming, budgeting, and other resource-allocating processes through which programs are implemented, and (2) costs should reflect a sensitivity to real-world cause-effect relationships. Although estimating difficulties exist for both acquisition and O&S costs, the latter are particularly troublesome in most life cycle analyses, and their realistic representation should be given first priority in developing improved models.

A single methodology is needed that will generate compatible estimates for all O&S elements, thus providing for more uniform treatment of the various elements than is possible with the present models. Although no single approach to cost estimating is appropriate for all elements, several could be included in one comprehensive model so that valid total cost estimates could be made with the most appropriate approach applied to each individual cost element. Since the idea of somehow reducing O&S costs is involved in most life cycle analyses, it is important to identify any aspects of the subject project that might actually achieve that objective. This can best be accomplished with a methodology based on a set of cost elements that can be accepted as standard for the widest possible range of Air Force systems and decisions, using the terminology of budgeting and accounting: program elements, appropriations, element of expense and investment codes, and functional account codes.

The second requirement noted above—sensitivity to cause-effect relationships—has two implications: (1) More thorough research is needed on causal relationships and the identification of cost driving factors, and (2) future improvements to estimating methods must take account of institutional policies and procedures as well as the physical characteristics that affect resource demand. Allocation or proration methods that simply spread costs in proportion to some convenient system variable (which may have little relationship to the real cost driving factors) should be avoided. Forcewide policies, such as standard organizational structures

and established procedures for maintaining and operating aircraft, should be included explicitly in the estimating model. Organizational structure, for example, may be more important in setting resource levels for a system than variations in the reliability and maintainability characteristics of some subsystems and components. Visibility at the subsystem and component level is another requirement if LCC models are to be used in evaluating alternative hardware designs. Some of this visibility is available in existing models, but it needs to be combined with more thorough consideration of the organizational structure and the tasks, functions, and procedures that make up the overall operations and support concept for a system.

Short Term Improvements

With sufficient effort and time, it should be possible to overcome the main methodological problems and data deficiencies of life cycle cost analysis. Meanwhile, results obtained using existing models and generalized estimating techniques should be viewed critically. The deficiencies in an estimate can be illuminated by using the information presented in our model evaluations, but the principal protection against these deficiencies is careful supporting work by the analyst, supplementing or even substituting for formal models by providing corroborative evidence based on analogous situations and relevant historical data.

Historical data to corroborate LCC estimates have generally been difficult to find, largely because the cost categories used in LCC models are incompatible with functional and accounting categories used to record manning and cost information. Our life cycle cost element definitions can help alleviate this difficulty—at least for direct (wing/squadron level) operating costs and depot maintenance costs. The use of these definitions, even within the framework of current LCC models, can help make cost estimates internally consistent and should facilitate tracking the actual cost consequences of a proposal after it is implemented.

For indirect support costs such as formal training, base operations, and PCS travel, improved conventions could be established for attributing total force support costs to weapon systems. These conventions should approximate the procedures used to establish actual manpower authorizations and budgets. Although support costs estimated in this way can never be fully valid in an absolute sense, they should at least be internally consistent and not at variance with the way in which the support establishment perceives and reacts to changes in weapon system requirements.

Generalized models may never, by themselves, be fully satisfactory for all LCC studies. Some supplementary analysis may always be advisable. What this evaluation has made clear is that until substantially improved models can be developed, supplementary work will be an essential part of most life cycle analyses.

APPENDIX A

USAF PROGRAM ELEMENTS, APPROPRIATIONS, AND LIFE CYCLE COST ELEMENT DEFINITIONS

Section III briefly described the set of life cycle cost elements used in this study. This appendix presents the full definitions of these elements and discusses the USAF program structure and budget/appropriation structure on which the definitions are based. The definitions shown here appear to us to be the most suitable for life cycle analysis, but they are not the only possible definitions. It is important to establish standard definitions, so that one can see where an LCC estimate fits in relation to total USAF resources, but the definitions eventually adopted by the Air Force need not be exactly the same as those presented in this report.

At the highest level of aggregation, the relevant costs in life cycle analysis are the incremental USAF budget costs incurred by adding an aircraft system to the force and operating it over a period of time. We specify *USAF budget costs*, because we are primarily interested in what funds the Air Force will have to spend if a decision is made to take a specific course of action. We specify *incremental costs*, because we are interested in the costs resulting from the decision. In contrast, a cost accounting concept would include allocated overhead costs that would normally not be affected by the decision. The baseline from which incremental costs are calculated must be understood before they can be defined. The baseline is usually the currently planned force. In most cases, the new weapon system is a relatively modest addition to the total force or is intended to replace an existing system. Under these conditions the incremental costs will consist of the direct costs of the system and its major variable indirect support costs (i.e., marginal changes in base operations, central training, supply, and other such support costs). The weapon system decision does not affect the fixed costs of opening bases, operating the Air Force Logistics Command and Air Training Command, etc., except occasionally (e.g., a system employing a new basing concept might require an expansion, or permit a reduction, in "fixed" base facilities). The framework of LCC categories described below applies primarily to the usual variable costs. Cases involving changes in forcewide basing or support structure may require some additional cost elements to capture the costs of making those changes.

USAF PROGRAM STRUCTURE

The USAF Force and Financial Program (F&FP) divides Air Force activities and organizational units, manpower authorizations, and budget costs into 10 major force programs (MFPs) with program elements (PEs) within the MFPs. Associated with each PE are specific equipment, facilities, manpower, and costs. The costs are divided into appropriation categories and into cost elements (CEs) within appropriations.

In many cases we can define life cycle cost elements for aircraft systems directly in terms of F&FP PEs. This can be done readily for the direct costs of weapon

systems; but for indirect support costs, PE definitions alone are not sufficient to define the costs attributable to a specific system. It is possible, however, to specify the PEs that cover forcewide, total costs in each support category. The task of identifying the fixed and variable components of cost within each support cost category was not undertaken here, as it is more appropriately considered after the composition of the categories is formally established.

Table A.1 presents a list of program element categories (with examples of specific PEs) that can be matched with certain individual LCC elements or subsets of LCC elements. The PEs listed here and the comments presented below are based on the F&FP of February 1978. Changes are made to this structure from time to time; hence adjustments to the PE categories may occasionally be required to bring them into conformance with the latest program structure.

Primary Program Element and Combat Crew Training

The first category in Table A.1 covers the primary direct costs of a weapon system. The primary program element (PPE) covers procurement costs and the direct (base level) operating costs of deployed units. Development costs may be identified with the PPE (for systems approved for production) or in a separate PE in MFP 6-Research and Development (for systems not yet approved for production). Aircrew training or combat crew training (CCT) operations may be funded in the PPE or in a separate training PE in the same MFP. The example training PEs listed under this category (27597 and 41897) include CCT units for virtually all the major aircraft systems in their major force programs. Procurement costs of CCT aircraft are usually assigned to the PPE, rather than to the CCT PE. Taken together, the costs funded in the PPE, the training PE, and the MFP6 PE for a given aircraft system should equate with the life cycle cost elements Research and Development, Investment (except, possibly, for part of War Reserve Material costs), Deployed Unit Operations, Below Depot Maintenance, and Sustaining Investments (except for Training Ordnance).

Depot Maintenance

Although we have categorized depot maintenance costs as "direct weapon system costs" in Table A.1, these costs are not included in PPE or CCT program elements for most aircraft.[1] Depot maintenance costs for all active USAF aircraft—excluding Air Force Reserve (USAFR), Air National Guard (ANG), and Airlift Service Industrial Fund (ASIF) aircraft—are contained in PE 72207-Depot Maintenance Activities (Non-IF). Separate depot cost reports must be used to obtain information on depot maintenance costs for individual aircraft systems. The funding for an aircraft system's depot maintenance would normally be wholly contained in PE 72207, although the personnel who perform depot maintenance work are shown elsewhere in the F&FP—in PE 72007-Depot Maintenance Activities (IF). We explain this apparent contradiction later in this appendix, after we describe the appropriate breakdown of costs in the F&FP.

[1] The exceptions to this rule are the industrially funded airlift aircraft. PPE costs for these aircraft do include depot maintenance costs.

Table A.1

PROGRAM ELEMENT CATEGORIES AND EXAMPLE PEs

Direct Weapon System Costs
  Primary Program Element (PPE) and Combat Crew Training (CCT)
    27130--F-15 Squadrons
    27133--F-16 Squadrons
    41313--Advanced Medium STOL Transport (AMST)
    27597--Training-Tactical Air Forces
    41897--Training-Airlift Forces
    64228--AMST Development (R&D costs only)
    64229--F-16 Development (R&D costs only)
  Depot Maintenance
    72007--Depot Maintenance Activities (IF)
    72207--Depot Maintenance Activities (Non-IF)

Indirect General Support Costs
  Installations Support
    11894--Real Property Maintenance Activities (RPMA)-SAC
    11895--Command and Base Communications-SAC
    11896--Base Operations-SAC
    27594--Real Property Maintenance Activities-Tactical Forces
    27595--Command and Base Communications-Tactical Forces
    27596--Base Operations-Tactical Forces
  Depot Supply
    71111--Supply Depots/Operations (Non-IF)
    71112--Inventory Control Point Operations
    71113--Procurement Operations
  Second Destination Transportation
    78010--Second Destination Transportation
  Recruiting and Individual Training
    81711--Recruiting Activities
    81712--Advertising Activities
    81713--Examining Activities
    81714--Personnel Processing Activities
    84711--Recruit Training Units
    84721--Service Academy
    84722--Officer Candidate/Training Schools (OCS)
    84723--Reserve Officer Training Corps (ROTC)
    84724--Other College Commissioning Programs
    84731--General Skill Training
    84741--Undergraduate Pilot Training
    84742--Undergratuate Navigator/NFO Training
    84751--Professional Military Education
    84752--Other Professional Education
  Health Care
    87711--Care in Defense Facilities
    87713--Care in Non-defense Facilities
    87714--Other Health Activities
  PCS Travel
    88731--Permanent Change of Station
  Training Munitions and General WRM Equipment
    27161--Tactical AIM Missiles
    27162--Tactical AGM Missiles
    27599--Munitions Training Items
    28030--WRM-Ammunition
    28031--WRM-Equipment/Secondary Items

Indirect General Support Costs

The remaining PE categories in Table A.1 cover the costs that should be included in the life cycle cost elements Installations Support, Depot Supply, Second Destination Transportation, Personnel Training and Support, and Training Ordnance. A portion of the War Reserve Material (Support Investment) cost element may also be covered in the last PE category in our list (Training Munitions and General WRM). These are called indirect, general support costs, because the services and materials they cover are used jointly by many weapon systems and other Air Force activities. The PEs in each category should be used as the means of identifying forcewide, total costs in these categories.

Because the general support costs are indirect and jointly shared by many weapon systems (and other Air Force activities), there is no way to identify the "correct" general support cost attributable to a single weapon system. Some services in this category may be identified with a single system (e.g., a technical training course that pertains to skills required by only one system), but most general support services apply to items common to several systems or to personnel categories that are common to many different organizations. Only a portion of the cost of providing support services is sensitive to weapon system or force level decisions; there is a fixed "startup" cost that is insensitive to these decisions. The usual approach to this problem is to use conventions to estimate the marginal effect on a system category of a change in direct, weapon system requirements (e.g., marginal change in training costs as a function of the number of direct personnel). This report does not define these conventions explicitly, but they are an essential part of a complete and consistent framework for life work cost estimation.

The *Installations Support* category in Table A.1 includes a representative set of PEs for this category. The costs covered here are for base support activities, including Civil Engineering, Transportation, Services, Accounting, Personnel, and Communications. On each Air Force base these activities are funded by a single "host" command and are provided to all tenants on the base. The base support activities on all bases for a particular command are summed into a single set of Installations Support PEs. For example, PEs 27594 through 27596 cover the RPMA, Communications, and Base Operations costs for bases operated by Tactical Air Command (TAC), Pacific Air Forces (PACAF), and U.S. Air Forces in Europe (USAFE). A complete list of the relevant PEs for this category would include Real Property Maintenance Activities, Base Communications, and Base Operations PEs for all MFPs.[2] Only a portion of these costs is sensitive to changes in weapon systems and force levels, and there is no direct means of identifying the specific Installations Support cost associated with a single system. Thus conventions must be adopted to define weapon system costs in this category.

The PEs listed under the *Depot Supply* and *Second Destination Transportation* categories in Table A.1 appear to be the appropriate ones for these costs as defined in the CAIG Guide. As with Installations Support costs, these costs cannot be

[2] These appear explicitly in MFPs 1-5 and 7-9. AFSC base support costs are included in MFP 6, but there are no PEs with these titles in MFP 6. Alternative "Base Operating Support" definitions have been proposed that include PE 33112-Air Force Communications and PE 35114-Traffic Control, Approach, and Landing System. Although it is not unreasonable to include these PEs in the Installations Support category, their costs do not appear to be particularly sensitive to weapon system decisions; we have therefore left them out. Whatever definition is used, it should be applied consistently across all types of bases and across all types of tenants supported by these activities.

uniquely identified to specific weapon systems. Furthermore, no generally accepted conventions have been devised for this category.[3] Thus although the PEs can be used to define forcewide costs, the accuracy of a given technique for estimating weapon system costs in these areas cannot be assessed. Historical trends and future projections in the F&FP suggest that overall budgets for these activities are set at a policy-directed level of effort and are relatively insensitive to changes in weapon system characteristics and force levels.

The categories we have called *Recruiting and Individual Training, Health Care,* and *PCS Travel* are roughly equivalent to the CAIG Guide category called Personnel Training and Support. The PEs listed in these categories cover forcewide activities that either support Air Force personnel directly (e.g., Health Care) or are required to provide appropriate general training and career progression (including rotation of personnel through different duty assignments). As with other support cost categories, only a portion of these costs is sensitive to changes in weapon system manpower requirements, and conventions must be established to identify the costs attributable to a weapon system.

The *Training Munitions and General WRM Equipment* category in Table A.1 includes the PEs that cover the costs of items consumed in peacetime training activities and items stocked for use in wartime. Annual budgets for these items are established by a complex combination of training standards, wartime scenarios, and budgetary constraints. It is difficult to trace these costs to specific weapon systems without including the other factors as well; thus it is necessary to establish conventions rather than direct relationships to identify a weapon system's share of the costs in this category.

APPROPRIATIONS AND APPROPRIATION COST ELEMENTS

The appropriation/CE breakdown of costs within a program element can be used to identify the specific set of costs in the F&FP that should be associated with each life cycle cost element. Table A.2 lists the appropriations and CEs used in the LCC element definitions presented later in this appendix. This list does not show all cost categories that appear in the F&FP—only those that are essential to the LCC element definitions.

One major reason for the importance of the appropriation structure in viewing cost estimates is that it is an important facet of the accounting and control of expenditures in the Air Force. The F&FP program element structure is used directly in budgeting and accounting for costs in the operating cost appropriations. Thus it is possible to estimate, budget, and account for costs in similar categories where the LCC structure and program structure coincide (i.e., for direct weapon system operating costs). In addition to this, operating cost data directly relevant to some LCC categories can be collected from existing accounting systems.

In contrast to the operating appropriations, the development and investment appropriations are only partially tied to weapon systems and the F&FP program structure. Within these appropriations, budgeting and accounting are oriented

[3] The Air Force operating cost reporting system for aircraft (VAMOSC-AIRCRAFT) uses allocation rules to identify some portion of these costs to weapon systems. However, there is apparently no connection between these allocation rules and the programming/budgeting procedures used to establish forcewide resource requirements in this category.

Table A.2

APPROPRIATIONS AND KEY COST ELEMENTS FOR LCC ELEMENT DEFINITIONS

- Development and Investment Appropriations
  - 3600--Research, Development, Test and Evaluation (RDT&E)
  - 3010--Aircraft Procurement
    - Aeronautical Vehicle
    - Peculiar Support
    - Prior Year Credit
    - Advance Buy
    - Weapon System Initial Spares
    - Modifications
    - Modification Initial Spares
    - Component Improvement
    - Common AGE (costing)
    - Common AGE (new acquisition)
    - Common AGE (simulators)
    - Common AGE Spares
    - Replenishment Spares (costing)
    - Replenishment Spares (WRM)
    - War Consumables
    - Other Charges
    - First Destination Transportation
  - 3020--Missile Procurement
  - 3080--Other Procurement
    - Munitions and Associated Equipment
    - Vehicular Equipment
    - Electronics and Telecommunications
    - Other Base Maintenance and Support Equipment
  - 3300--Military Construction

- Operating Appropriations
  - 3400--Operations and Maintenance (O&M)
    - Civilian Personnel
    - Travel of Personnel
    - Transportation of Things
    - Standard Level User Charges
    - Other Utilities and Rents
    - Communications
    - Printing and Reproduction
    - Payments to Foreign Indirect Hire Personnel
    - Purchased Equipment Maintenance-Comm.
    - Purchased Equipment Maintenance-DMIF
    - Purchased Equipment Maintenance-Other
    - Other Purchases from Industrial Funds
    - Other Purchased Services
    - Aircraft POL
    - Other Supplies
    - Equipment
    - Other Expenses
  - 3500--Military Personnel
    - Air Force Personnel-Officers
    - Air Force Personnel-Airmen
    - Air Force Personnel-Cadets
    - Permanent Change of Station Travel
  - 4922--Air Force Industrial Fund
    - Depot Maintenance (DMIF)
    - Airlift Service (ASIF)
      - POL
      - Depot Maintenance
      - Civilian Personnel
      - Other Expenses

toward equipment end-items. It is fairly easy to identify direct system development and investment costs (because the end-items are directly associated with the weapon system), but other initial and sustaining investment costs (e.g., Common Aerospace Ground Equipment (AGE), Spares, War Consumables, etc.) are associated with end-items that may be common to many systems. The "cost" of replenishment spares as stated in the F&FP for a weapon system PPE only represents an estimate of the system's share of forcewide replenishment spares. The only way to tie actual expenditures back to weapon systems (or to PEs) is to identify all items purchased and the system(s) against which each type of item should be charged. This is a massive task, and even if it were routinely done, it still would involve somewhat arbitrary assignment of some costs. The dimensions of this problem are difficult to estimate, because the peculiar/common breakdown varies both by weapon system and by type of end-item (e.g., a large fraction of avionics equipment for current aircraft is "common," but a new system might use many new, peculiar avionics subsystems).

The Air Force Industrial Fund (AFIF) is a "revolving fund" (not an appropriation), which is not included as part of the Air Force's regular budget (total obligational authority). Costs shown under the AFIF cover activities or services performed by the Air Force for various "customers" (some of whom are other Air Force organizations) who reimburse the Air Force out of their own budgets. The Depot Maintenance Industrial Fund (DMIF) portion of the fund covers the cost of personnel, expense material, and contractual services for depot maintenance activities. Depot maintenance costs for all active USAF aircraft are reimbursed to the fund from the USAF Operations and Maintenance (3400) appropriation. These O&M costs are shown as a total (not broken down by aircraft system) in PE 72207-Depot Maintenance Activities (Non-IF). Total 4922-DMIF costs (including active USAF, USAFR, ANG, Airlift-IF aircraft, and non-AF customers) are recorded in the F&FP in PE 72007-Depot Maintenance Activities (IF). Pay and allowances for the civilian manpower authorizations associated with PE 72007 are included in the 4922 funding total for this PE instead of in the O&M appropriation.

The Airlift Service Industrial Fund portion of the Industrial Fund provides for reimbursement of costs incurred by Air Force airlift aircraft in carrying passengers and cargo for various customers (including other Air Force organizations). For analytical purposes the ASIF can be thought of as a substitute for the O&M appropriation for airlift aircraft.[4] Depot maintenance costs for these aircraft are included (under ASIF) in each airlift aircraft PPE instead of in PE 72207-Depot Maintenance Activities (Non-IF).

DEFINITIONS OF USAF AIRCRAFT LIFE CYCLE COST ELEMENTS

The definitions presented here for the life cycle cost elements are based on the definitions given in the CAIG Guide, with the addition of information from the program and budget structure as discussed above.

[4] However, CCT units for airlift aircraft are funded under the O&M appropriation.

Research and Development

Research and Development includes all costs of research and development activities conducted to prepare for weapon system production. Included are the cost of Air Force technical and management activities and the cost to the Air Force of contractor studies. Costs incurred prior to production approval appear in the F&FP in MFP 6. After production is approved, costs appear in the PPE with which the operating system is identified.

System Investment

System investment includes the flyaway cost (procurement cost) of the Aeronautical Vehicle, as defined in the F&FP, and all other costs of producing or procuring the aircraft (including in-flight hardware and software), managing the acquisition program, and delivering the aircraft to operational units. Included in these other costs are costs associated with the Component Improvement, Other Charges, and First Destination Transportation elements of the Aircraft Procurement appropriation. The Component Improvement Program funds GFAE improvements (primarily turbine engines) during aircraft production. Other Charges includes stock fund fuel (for use by the contractor for testing and for initial fill of aircraft prior to flyaway). It also includes the cost of ECM pods and alternate mission equipment (airborne photography, reconnaissance, etc.) used on the aircraft. First Destination Transportation is the cost of initial shipment of goods to the Air Force. The Prior Year Credit and Advance Buy cost elements included in the list in Table 3 (Sec. II) are time-phasing adjustments to the Air Vehicle cost to account for one-year advance funding requirements for long lead-time items.

The cost of managing the acquisition program includes the cost of operating the System Program Office. Because this cost is largely independent of weapon configuration,[5] it can be omitted when examining alternatives within a single aircraft development program. However, an acquisition program that is substantially larger or more complex than another will likely have a larger and more costly SPO.

Support Investment

Almost all Support Investment is associated with the PPE; exceptions are noted in the individual cost category definitions below.

Support Equipment

Support Equipment includes the cost of acquiring the initial inventory of support equipment and software, both common and peculiar, needed to operate or support aircraft and aircraft subsystems and support equipment. This consists of (1) peculiar support equipment identified with the weapon system and considered part of the weapon system cost, which is accounted for in the Peculiar Support cost element of Aircraft Procurement; and (2) in-service support equipment common to more than one type of aircraft, which is accounted for in the Common AGE

[5] All SPOs and other acquisition management activities of the Aeronautical Systems Division of the Air Force Systems Command are funded, generally at an overall level-of-effort, under PE 65806-Acquisition and Command Support.

(Aerospace Ground Equipment) cost element of Aircraft Procurement. Replacement support equipment costs funded as either Common AGE or Peculiar Support are excluded (see Replenishment Ground Support Equipment).

Training Equipment and Services. The cost of acquiring and installing initial training equipment, including weapon system peculiar simulators, and the cost of initial training services. The latter includes the cost of factory training provided by contractors at their facilities to qualify an initial cadre of skilled personnel to operate and maintain the equipment and initially man Air Force weapon system-related courses.[6] Excluded are trainee pay and allowances and travel cost (see Individual Training).

The cost of initial training services is, in part, a function of the weapon system's manpower requirements, but for analytic purposes, the determination of system manpower requirements is considered under a separate category (see Deployed Unit Operations and Below Depot Maintenance).

These costs are funded under the Aircraft Procurement appropriation. Most are included in the Peculiar Support cost element.

Documentation. The cost of gathering, storing, reproducing, and disseminating technical data describing the weapon system and data needed for program management, and the costs of preparing, updating, and reproducing publications such as technical manuals needed to operate and maintain the system. These materials are normally furnished by the contractor(s) and are funded under the Peculiar Support cost element of Aircraft Procurement.

Documentation and updating costs after production is complete are O&S costs and are excluded from this category (see Technical Support).

Initial Spares and Repair Parts. The cost of procuring aircraft, AGE, and training device spares and repair parts that are

1. Investment items (reparable items that are centrally managed with individual item reporting).
2. Support for new aircraft for an initial period of operations, normally not more than two years. (This is a definition by convention; an analysis should assess total spares—initial plus replenishment.)

These spares are funded by the Weapon System Initial Spares and Common AGE Spares cost elements of the Aircraft Procurement appropriation. Some items may be funded by the Other Charges cost element.

Spare Engines. The cost of spare engines and spare engine module components to support the wartime flying program, including war reserve requirements. These spares are funded by the Weapon System Initial Spares cost element of the Aircraft Procurement appropriation.

Facilities (Non-production). The cost of construction, conversion, or expansion of government facilities for operation and support of the weapon system. This work is usually accounted for under the Military Construction appropriation. Facilities projects costing no more than $75,000 may be funded under the Other Purchased Services cost element of the O&M appropriation.

[6] This cost element does not include general recruiting and training costs for the "first set" of personnel for the full force. Such costs are assumed to be included (when time phasing is done properly) in the O&S cost category Individual Training and in CCT operating costs.

War Reserve Material (WRM). The cost of establishing or increasing stocks to support wartime requirements.

a. **Spares and Repair Parts.** Funded in Aircraft Procurement, under Replenishment Spares (WRM) and Weapon System Initial Spares.
b. **Munitions.** Provided for in program element 28030, WRM Ammunition, and funded in the Other Procurement appropriation.
c. **Missiles.** Funded in the Missile Procurement appropriation, and identified with program elements 27161, Tactical AIM Missiles, and 27162, Tactical AGM Missiles. Some large or relatively expensive airborne missiles (e.g., Maverick, SRAM) are funded in separate program elements of their own. If an aircraft system generates requirements for increased war reserve stocks for these missiles, the costs would appear in the individual PEs rather than in the Tactical AIM and AGM PEs listed above.
d. **Tanks, Racks, Adapters & Pylons.** Items of equipment stocked to replace items that would be expected to be consumed in wartime operations. This cost is provided for under the War Consumables cost element of Aircraft Procurement. The cost of ECM pods and alternate mission equipment stocked for wartime use would be included in the Other Charges cost element of Aircraft Procurement.

Deployed Unit Operations

A deployed unit is any unit (wing, aircraft squadron, etc.) operating in the field for combat, training (CCT), or any other operating purpose. In the F&FP and in the Base Operating Budget Status Report, RCS HAF-ACF(Q) 7146, deployed unit costs would be charged against an aircraft squadron program element (PPE) or against a training (CCT) PE. Depending on the purpose of the cost estimate, these costs may or may not include costs associated with support aircraft operated by the deployed unit.

Aircrews. Pay and allowances[7] for all aircrew personnel required to meet combat and training requirements plus such administrative requirements as leave. Aircrews are identified with manpower and organization function codes (FC) 311x and 3718, as defined in AFM 300-4.[8] This cost is accounted for under the Military Personnel appropriation.

Command Staff. Pay and allowances for all personnel required for flying supervision: command, operations control, planning and scheduling, flight safety, quality control on aircrew training and flying proficiency; includes combat and squadron commanders and their staffs. This cost is accounted for under the Military Personnel and O&M appropriations. The functional categories included are wing commander, vice commander, and executive assistant aides and secretaries (FC 1010); personnel assigned to flight safety (FC 1061); operations staff (FC 13xx less 1311 and 1330), and mission equipment personnel other than aircrews (FC 3100 or

[7] The term "pay and allowances" for military personnel covers costs funded in the Military Personnel appropriation, under the cost elements Pay and Allowances-Officers, and Pay and Allowances-Enlisted. For civilian personnel, it covers costs funded in the Operations and Maintenance appropriation, under the cost element Civilian Personnel and Payments to Foreign Indirect Hire (FNIH) Personnel.

[8] Department of the Air Force, *Data Automation Data Elements and Codes*, AF Manual 300-4, Vol. XII—General Purpose, ADE FU-500, March 10, 1976.

3718, the squadron commander and operations officer; and FC 3101 or 3701, first sergeant and other squadron administration personnel).

Aircraft POL. The cost of aviation POL for support of peacetime operations; includes consumption in flight and on the ground plus allowance for distribution, storage, and spillage. This cost is accounted for in the Aircraft POL cost element of the O&M appropriation. POL expenditures are accounted for in the accounting system under Elements of Expense/Investment Codes (EEICs) 601, 698, and 699.[9]

Security. Pay and allowances for aerospace system security personnel, including both the actual security force and related administrative personnel (FC 435X, Aircraft and FC 438X, Nuclear Weapon Storage Areas). This cost is accounted for under the Military Personnel appropriation. Civilian manpower is not usually authorized for this function.

Other Deployed Manpower. Pay and allowances for other personnel assigned to deployed units and charged to the appropriate PPE or CCT PE, including Information (FC 104X), Logistics (12XX), and Safety (106X) other than Flight Safety (1061). Includes student aircrew personnel assigned to combat crew training squadrons. This cost is accounted for under the Military Personnel and O&M appropriations.

Miscellaneous Operations and Maintenance. All deployed unit operating costs not accounted for by other cost elements are collected together as Miscellaneous Operations and Maintenance costs. These costs are funded under the Operations and Maintenance appropriation. Included are the costs of TDY travel, utilities, purchased services, and miscellaneous supplies and equipment. The costs may appear in any O&M cost elements except Civilian Personnel or Aircraft POL.

This cost category is called "personnel support" in the CAIG Guide, but the term "Miscellaneous O&M" is used here in order to account for costs that are not necessarily personnel-related. Costs in this category are often estimated on a cost-per-man basis, but manpower requirements are estimated separately under the categories Aircrews, Command Staff, Security, and Other Deployed Manpower, described above.

Below Depot Maintenance

Below Depot Maintenance includes the cost of Air Force manpower and contractual support for base-level maintenance of aircraft, support equipment, training devices, and ordnance. These costs are associated with an aircraft squadron program element (PPE) or with a CCT program element. (For analytical purposes, contractual support costs should be divided among the appropriate manpower and material cost subcategories listed below. Contractual support costs for current systems are normally accounted for under the Purchased Equipment Maintenance cost element of Operations and Maintenance.)

Aircraft Maintenance Manpower. The cost of personnel performing maintenance and general support of assigned aircraft, support equipment, and training devices. Training devices associated with deployed units are maintained by personnel assigned to the aircraft maintenance organization but not separately identified. Aircraft maintenance activities are performed by personnel assigned to aircraft

[9] AFM 300-4, Vol. X—Comptroller, ADE EL-191.

squadrons (unit aircrew life support, FC 3102), organizational maintenance squadrons (all FC 22XX except 2230, Support Equipment, and 225X, Base Flight and Transient Aircraft), field maintenance squadrons (FC 23XX except 234X, AGE), and avionics maintenance squadrons (FC 24XX except 2450, PMEL; 2461, Avionics AGE; and 2470, Avionics AGE). Support equipment is maintained by the PMEL and AGE shops: 2230, 234X, 2450, 2461, and 2470. Included are the pay and allowances of personnel assigned to the Chief of Maintenance functions, as defined in AFM 66-1, to the extent these functions relate to aircraft maintenance rather than ordnance maintenance. Typically Chief of Maintenance (FC 21xx) personnel are assigned to a wing headquarters, but they may be at a lower level in small organizations.

Ordnance Maintenance Manpower. The cost of personnel performing maintenance and service functions for munitions, missiles, and related systems. These personnel are assigned to Airborne Missile Maintenance squadrons (FC 248X) and/or Munitions Maintenance squadrons (25XX). Included are the pay and allowances of personnel assigned to the Chief of Maintenance functions, as defined in AFM 66-1, to the extent these functions relate to ordnance maintenance rather than aircraft maintenance.

Maintenance Material. The cost of expense material used in maintenance. This includes spares and repair parts that are (1) non-reparable or (2) reparable but not centrally managed with individual item reporting. This spares cost is reported in the accounting system under EEIC 605 (System Support Division, AFSF), 609 (General Support Division, AFSF), or 61X (Base Procured Non-Stock Fund Material for Direct Consumption). Also included in this element are packaged oil and lubricants, which are charged to EEIC 602 and are obtained from the General Support Division of the stock fund.[10] The O&M appropriation provides for this cost under the cost element Other Supplies. Additional maintenance material expenses may be incurred in EEICs 62X and 63X, which are covered in the Equipment cost element of O&M.

Miscellaneous Operations and Maintenance. All other operating costs of base level maintenance organizations not covered under the Maintenance Manpower and Maintenance Material categories above. See comments under the Miscellaneous O&M category for Deployed Unit Operations.

Installations Support

Installations Support cost is the variable cost of manpower, materials, and purchased services used in supporting the operation of Air Force bases and the tenants that occupy them. Organizationally, these activities consist primarily of those under the supervision of the Combat Support Group. They include the functions performed by the Communications Squadron, Civil Engineering Squadron, Supply Squadron, Services Squadron, Security Police Squadron (excluding weapon system security), Transportation Squadron, and that portion of the Wing Headquarters organization not charged to mission elements (i.e., accounting, personnel, etc., but not wing commander, operations staff, or chief of maintenance). Transient aircraft maintenance, which is handled normally by the Field Maintenance Squadron, is also counted as part of Installations Support. These functions support all

[10] AFR 173-10, Vol. I, p. A-11.

tenants on a base, but there is no way to identify them uniquely to specific tenants except by the adoption of conventions for allocating their costs to the tenants. Usually it is assumed that only a portion of Installations Support cost of a base varies with the mission population (and hence is attributable to tenants). The rest of the cost is assumed to be related to characteristics of the base itself and is, therefore, "fixed" with respect to weapon system changes.

These costs are accounted for under Real Property Maintenance Activities, Base Communications, and Base Operations program elements. The materials and purchased services costs included in this category include miscellaneous O&M costs sometimes referred to as "personnel support" costs, which generally vary with the number of mission personnel supported but are not restricted to expenses that are personnel-related. Base Operating Support (BOS) and Real Property Maintenance Activities (RPMA) costs are sometimes addressed as separate cost elements, but the factors that drive these costs are imperfectly understood. Since current techniques do not provide a very good means of separating the factors that may affect BOS and RPMA costs differently, Installations Support cost can be treated as a single category without any loss of accuracy.

Base Operations program elements generally include costs in the Military Construction and Other Procurement appropriations (the latter are primarily Vehicular Equipment and Base Maintenance and Support Equipment costs), but Air Force accounting systems do not provide a satisfactory means of tracking all expenditures in these areas back to specific bases or to systems supported on the bases. On the whole, requirements in these areas are probably not very sensitive to changes in mission population, and they can therefore usually be omitted as a component of weapon system Installations Support costs.

Depot Maintenance

Depot Maintenance includes the cost of manpower, material, and contractual services needed to perform aircraft, aircraft component, and aircraft support equipment maintenance and to install modifications at DoD centralized repair depots and contractor repair facilities. Each weapon system's depot maintenance cost is accounted for as part of the total cost for the Depot Maintenance Activities (Non-IF) program element, 72207. These costs are funded by the Military Personnel and O&M appropriations. Most of the civilian personnel engaged in depot maintenance work are authorized under PE 72007-Depot Maintenance Activities (IF). They are funded under the DMIF account rather than under O&M. The Purchased Maintenance (DMIF) costs shown under PE 72207 represent reimbursements to the DMIF for depot maintenance work. Depot maintenance work performed by contractors is also funded under the DMIF appropriation. For analytical purposes, contractor costs should be separated, as are organic depot maintenance costs, into manpower and material cost elements.

Manpower. The cost of labor needed to perform major overhaul, repair, modification, inspection, and storage and disposal of aircraft and aircraft components and support equipment. Includes variable cost of overhead for organic repair.

Material. The cost of expense material consumed in depot overhaul, repair, inspection, storage, and disposal processes. This includes spares and repair parts that are (1) non-reparable or (2) reparable but not centrally managed with individual item reporting.

Depot Supply

Depot Supply includes the cost of manpower, material, and contractual services needed to buy, store, package, manage, and control the supplies, spares, and repair parts used in operating and maintaining aircraft and aircraft components and support equipment; and to provide service engineering and technical data support for aircraft systems. These costs are funded by the Military Personnel and O&M appropriations.[11]

Material Distribution. The cost of manpower and material needed to fill requisitions for supplies, spares, and repair parts, including the cost of receiving, unpacking, storage, inspection, and packing and crating. These costs are identified with program element 71111, Supply Depots/Operations. Resources for these activities appear to be programmed at a level of effort that is essentially independent of weapon system force levels, and the factors that drive requirements in this area are not easily identified to weapon systems.

Material Management. The cost of manpower and material needed to manage the procurement of supplies, spares, and repair parts and to maintain control and accountability of these assets. These costs are included in functions the Air Force calls "procurement operations" and "material management." Procurement operations consists of prime procurement and contract management. Prime procurement is accomplished by AFLC and consists of the negotiation, award, amendment, revision, and termination of contracts for procurement of electronic systems, spares, and modifications and overhauls. Contract management, which is performed by both AFLC and AFSC, consists of a variety of services that oversee contractor performance. Procurement operations is accounted for in program element 71113, Procurement Operations.

As defined by the Air Force, the functions of "material management" are computation of requirements, provisioning, requisition processing, cataloging and standardization, and material issue and accountability. The costs of these activities are covered by program element 71112, Inventory Control Point Operations. The activities covered in this category are organized around specific contract arrangements, equipment items, and spare parts. A few of these may be peculiar to one weapon system, but most of them are common to many, and no comprehensive procedure exists today to relate overall resource requirements in this area to weapon system characteristics. On a forcewide basis the level of effort devoted to these functions appears to be relatively insensitive to weapon system force levels.

Technical Support. The cost of sustaining (service) engineering, technical data, and documents needed to perform sustaining engineering and maintenance on aircraft components and support equipment. The Air Force considers this function to be part of the material management function, which is covered in program element 71112, Inventory Control Point Operations.[12]

[11] The costs in this category represent forcewide support activities that have only recently come to be regarded as components of weapon system cost. On a forcewide basis, these costs appear to be funded on a level-of-effort basis. No integrated effort has yet been undertaken to determine what factors drive costs in this category, and the allocation rules that have been proposed for use in weapon system and life cycle costing are apparently not related to any practices or procedures used to set the budget and manning levels for these activities.

[12] *DOD Handbook 7045.7*, Vol. I, Book No. 5, p. I-7-2, August 15, 1972; *DOD Appropriations for FY 1977*, Part 3, pp. 228-229.

Second Destination Transportation

Second Destination Transportation for a weapon system includes (1) transportation of weapon system repair parts from CONUS stock points to depot and base-level maintenance activities and (2) round-trip transportation of engines and engine components, ground support equipment, and reparable secondary items between depot maintenance facilities and operational units or CONUS stock points. Program element 78010, Second Destination Transportation, includes movement of material by commercial transportation, commercial contractual airlift within CONUS, and by Military Airlift Command and Military Sealift Command to overseas areas. Also included are the costs of port handling, stevedoring, and demurrage. Material moved includes general cargo, missiles, special weapons, munitions, exchange service items, APO mail, and motion picture service items. Excluded is the cost of transporting material associated with PCS moves.[13]

The relationship between forcewide Second Destination Transportation costs and weapon system characteristics is not clear. The number of items to be transported is driven by such factors as system reliability, maintenance concept, and basing posture; but budget levels for this category appear to be established at a relatively constant level of effort. Hence, estimates of the Second Destination Transportation cost attributable to a weapon system may have little relationship to the way in which resources are actually allocated and utilized.

Personnel Training and Support

Individual Training. The variable cost of personnel acquisition and training (identified with MFP 8), including: recruit acquisition (program elements 81711 through 81714), recruit training (82711), ROTC (82727), service academy (82728), specialized training (82782), professional training (82783), and undergraduate pilot and navigator training (Flight Training, 82784). Costs included are trainee pay and travel costs, instructor pay, and the cost of all supplies, materials, equipment, and contracted services needed to conduct or support training. Annual training costs attributable to a weapon system represent the variable costs of initial training for personnel to replace those who (on the average) are expected to leave the Air Force each year, and advanced technical and professional training to sustain the skill levels required for the types of personnel required by the system. This category does not include aircrew advanced training costs (assumed to be captured in CCT costs).

The cost of conducting a training program is driven by the number of personnel to be trained and by the techniques and procedures used to accomplish the training. The number of trainees is driven strongly by the weapon system's manpower requirements, but estimating those requirements is considered to be a separate task from that of estimating costs for this cost element.

Simulators for undergraduate flight training and replenishment spares for training aircraft are funded under the Aircraft Procurement appropriation. Other training costs are funded by the Military Personnel and O&M appropriations.

Health Care. The variable cost of medical support for deployed unit personnel, base maintenance personnel, base support personnel, and trainees, including

[13] *DOD Appropriations for FY 1977*, Part 3, p. 233.

medical personnel pay and allowances, cost of medical material, and the cost of all other supplies, materials, equipment, and purchased services needed to provide health care. Care in Defense Facilities (87711), Care in Non-defense Facilities (87713), and Other Health Activities (87714) are the three program elements with which these costs are identified.

PCS Travel. The cost of PCS moves for deployed unit personnel, base-level maintenance personnel, installations support personnel, training personnel, and medical personnel. The program element Permanent Change of Station (88731) collects these costs for all Air Force military personnel.

Sustaining Investments

Replenishment Spares. The cost of procuring aircraft, support equipment, and training device spares and repair parts that are

1. Investment items (reparable items that are centrally managed with individual item reporting).
2. Support for in-service aircraft after an initial period of operations (normally not more than two years), during which the aircraft is supported by initial spares. (This is a definition by convention; analyses should assess total spares requirements—both initial and replenishment.)

Modifications. The cost of modification kits and modification initial spares for aircraft, support equipment, and training equipment. The modifications included are those needed to achieve acceptable safety levels, overcome mission capability deficiencies, improve reliability, or reduce maintenance costs. Excluded are modifications that are undertaken to provide operational capability not called for in original design or performance specifications. The Modification and Modification Initial Spares cost elements of the Aircraft Procurement appropriation include modifications for all these purposes. The costs are usually identified with the PPE, but they may also appear in the CCT program element.

Replenishment Ground Support Equipment. The cost of replenishing the inventory of support equipment that is needed to operate or support aircraft and aircraft subsystems or support equipment. This consists of replacements for support equipment peculiar to the weapon system, which are funded under the Peculiar Support portion of Aircraft Procurement (if the aircraft is still in production) or under Common AGE (if the aircraft is out of production); and replacements for in-service support equipment common to more than one type of aircraft, which are accounted for under the Common AGE portion of Aircraft Procurement. Initial support equipment funded as either Common AGE or Peculiar Support is excluded. (See Support Equipment under Support Investment.) Common AGE costs shown for an aircraft PPE in the F&FP may include the cost of new, whole simulators if they are to be procured after the aircraft is out of production. But normally, for a new aircraft system, all simulator costs would be included in the Support Investment LCC category (Peculiar Support cost element of Aircraft Procurement).

Training Ordnance. The cost of replacing or increasing stocks of ordnance expended by the operating unit during peacetime flying operations for the purpose of sustaining aircrew proficiency in weapon delivery techniques.

a. **Munitions.** Training munitions are funded by the Other Procurement appropriation. This cost appears to be entirely associated with general purpose forces and is accounted for in program element 27599, Munitions Training Items.

b. **Missiles.** Training missiles are funded by Missile Procurement and identified with program elements 27161, Tactical AIM Missiles, and 27162, Tactical AGM Missiles.

APPENDIX B

ASSESSMENT OF THE COST ESTIMATING CAPABILITY OF MODELS USED IN USAF AIRCRAFT SYSTEMS LIFE CYCLE ANALYSES

This appendix presents the detailed model evaluation that led to the results in Sec. III. For each cost element, as defined in Appendix A, each model was rated as to how well it represents known or anticipated effects of conceivable weapon system changes on absolute incremental cost.

The first step in the evaluation was an identification of cause-effect relationships for each driving factor/cost element combination. This involved the compilation of a list of specific causative agents—factors that would be directly responsible for the expected cost effects. After the cause-effect relationships were identified, each model was rated as to its ability to represent these relationships. Separate ratings were developed for each model's coverage of each driving factor/cost element combination. The evaluation considered each model's input parameters and its algorithms. The input parameters were examined to determine whether or not they are capable of describing the relevant causative agents. The algorithms were evaluated as to how realistically they relate the estimated cost to the causative agents, i.e., how well they capture the real-world, cause-effect relationships.

A discussion of the relevant cause-effect relationships and the applicable models is presented below for each of the cost elements. In most cases a summary table lists typical causative agents (if any), the applicable models, and the ratings assigned to the models. The ratings shown in the tables correspond to the color-coded ratings in Sec. III. Good coverage is the rating awarded when the expected relationships are handled adequately by a model. Fair coverage is an indication that the model handles the relationships to some degree, but does not address all important factors (or does not fully cover the cost element). A poor coverage rating is assigned where the model either (1) deals with only a minor part of the expected cost effect or (2) deals with the cause-effect relationship in a way that is possibly misleading or (3) has an unknown (or obscure) relationship to the content of the cost element as defined here (e.g., see discussions of the BACE and CACE models' coverage of "miscellaneous O&M" costs, and the LSC model's coverage of training costs). Where the model covers a cost element by using a "throughput" (externally calculated and merely displayed or added to other results by the model), the evaluation treats it as no coverage. The implications for a model's cost estimating capability are clear where ratings of good, poor, or no coverage have been assigned. But for combinations that are rated only fair, no firm rules can be drawn. In general, if in a given application the major cost effects fall into categories for which only fair coverage is indicated, these cost estimates should be treated as risky.

RESEARCH AND DEVELOPMENT

The specific causative agents and models applicable to research and development costs are summarized in Table B.1.

Table B.1

RESEARCH AND DEVELOPMENT COST DRIVERS

Driving Factor	Causative Agent	Applicable Models
Reliability & maintainability	Direct interest in R&M	PRICE-F
Physical characteristics	Type of materials, complexity of design, commonality	DAPCA-F PRICE-F
Maintenance concept	None	----
Supply support concept	None	----
Training concept	None	----
AGE concept	None	----
Crew size & composition	None	----
Force size & activity rate	None	----
Basing/deployment concept	None	----
Mission type and profile	Requirements associated with mission type	DAPCA-F

[a]The letter following each model name represents the rating assigned to the model's coverage of the driving factor: G stands for good coverage, equivalent to green in Fig. 1; F stands for fair coverage, equivalent to yellow; and P stands for poor coverage, equivalent to red.

Cause-Effect Relationships

Research and development (R&D) costs should vary with the weapon system's sophistication or complexity as reflected in R&M characteristics, physical characteristics, and mission type.

Reliability and Maintainability. The cost of R&M development and R&M program management will vary with the emphasis placed on desirable R&M characteristics.

Physical Characteristics. The type of structural materials used affects the costs associated with materials research and with the development of materials handling techniques. Complexity, as reflected in the number of parts, may affect the scope of development work. The use of parts previously developed for other systems could lead to lower development costs than would be incurred for an all-new system.

Mission Type and Profile. Development costs may be affected by mission type; i.e., combat aircraft could be more complex and therefore more costly to develop than support aircraft. The full range of such effects has not yet been completely and specifically identified.

Several other driving factors—namely the maintenance, training, AGE, and basing and deployment concepts—may be important parts of a development program[1] in the following ways:

1. The design of aircraft hardware should accommodate the level of maintenance support specified for each base or deployed operating site.
2. The techniques used in diagnosing failures should drive the design of the aircraft and the design or selection of AGE.
3. The cost of developing training devices will vary with the number of different types of training courses or on-the-job (OJT) training activities for which such devices are developed.
4. Requirements or constraints on the number or types of support equipment can affect aircraft design—as in the use of built-in test equipment as an alternative to ground support equipment.
5. The cost of flight testing could be affected by the need to exercise new support concepts.

Because it is not clear that R&D cost is significantly affected by these considerations or that such effects can be identified and treated in a generalized cost estimation procedure, they are not considered explicitly in this analysis as driving factors for R&D *cost.* Some of their effects may be translated into (and therefore implicitly accounted for through) physical characteristics or R&M requirements.

Applicable Models

DAPCA and PRICE address development costs related to the final configuration; research and early development costs are not covered. Since DAPCA does not cover avionics costs, and PRICE is primarily an avionics cost model, neither model by itself provides better than fair coverage of any driving factor. Although the combined capability of DAPCA and PRICE covers all aircraft systems, it is rated only fair because of the causative agents not covered and because of the lack of definite information about the PRICE methodology.

DAPCA's coverage of physical characteristics is rated fair because it is sensitive to some causative agents but omits others. Weight, speed, and engine thrust are major input parameters for DAPCA's airframe and engine estimates; these may provide some implicit sensitivity to structural material and complexity. DAPCA does not address commonality. It estimates lower flight test costs for cargo aircraft than for other types, providing limited sensitivity to mission type.

[1] Their potential effect on R&D cost is largely unknowable, however, because the level of effort devoted to them may be a management decision that is independent of the types of concepts considered.

In the absence of detailed information on the PRICE algorithms, they have been assumed to give fair coverage of all driving factors they address. PRICE accepts input describing redundancy and a reliability profile related to the platform. This model also uses the number of electronic components and other inputs that define complexity and the type of structural material.

SYSTEM INVESTMENT

Flyaway cost is the only part of System Investment that is or can be expected to be dealt with by generalized models. Other system investment costs are small or independent of aircraft program changes. The relevant causative agents and models are summarized in Table B.2.

Table B.2

SYSTEM INVESTMENT COST DRIVERS

Driving Factor	Causative Agent	Applicable Models
Reliability & maintainability	Component reliability redundancy	PRICE-F
Physical characteristics	Weight, speed, type of materials, commonality, design complexity	PRICE-F, DAPCA-F
Maintenance concept	Type and amount of work at each maintenance level	None
Supply support concept	None	----
Training concept	None	----
AGE concept	Functions performed by AGE, self-test	None
Crew size & composition	Crew accommodations, functions performed by crew	None
Force size & activity rate	Production quantity and rate	PRICE-F, DAPCA-F
Basing/deployment concept	None	----
Mission type and profile	Requirements associated with mission type	DAPCA-F

Cause-Effect Relationships

Reliability and Maintainability. Hardware with "good" R&M characteristics tends to cost more than hardware with "poor" R&M; e.g., redundant systems have more components than non-redundant systems and therefore cost more.

Physical Characteristics. The analysis behind DAPCA found that weight, speed, and thrust are physical characteristics related to flyaway cost. The type of material used may also affect the cost of manufacture. The unit cost of components and subsystems may be affected by whether or not they are used on other aircraft. Overall design complexity may affect the ease or difficulty of manufacturing.

Maintenance Concept. A decision on how much and what type of maintenance to perform at each echelon should be reflected in component design parameters that affect flyaway cost.

AGE Concept. The type of test equipment to be provided (i.e., the functions to be performed by the equipment) should affect design and therefore unit cost. A decision to minimize peculiar support equipment can drive the amount of special on-aircraft test equipment, thus increasing flyaway cost; e.g., self-start capability versus support equipment.

Crew Size and Composition. For a given size and weight vehicle, a change in crew size means a change in design that could affect flyaway cost; a change in crew composition could cause a change in on-board equipment (different avionics) that would change flyaway cost.

Force Size and Activity Rate. Unit flyaway cost varies with production quantity and production rate. Total fleet flyaway cost obviously depends on the number in the fleet.

Mission Type and Profile. The type of mission affects aircraft design and thus can affect flyaway cost. The nature of this relationship has not been established, and it may not be amenable to generalized modeling except for gross differences in mission type (e.g., cargo versus fighter aircraft).

Applicable Models

DAPCA and PRICE address System Investment cost. DAPCA covers the major drivers of airframe and engine costs, but it does not cover all of the driving factors and does not estimate avionics cost. PRICE is primarily an avionics model. The combined DAPCA/PRICE coverage is only fair because of the causative agents not covered and because of the lack of detailed information needed for a thorough evaluation of PRICE. The evaluated models are not sensitive to maintenance concept, AGE concept, or crew size and composition. While both consider some physical characteristics, neither addresses commonality.

DAPCA estimates procurement cost as a function of weight, thrust, speed, and mission type. The weight variables provide indirect sensitivity to type of material. DAPCA uses different quality control methodologies for cargo aircraft and other aircraft types; but since this is only part of the cost element, the model's coverage of mission effects is rated only fair. Both DAPCA and PRICE include an accounting of production quantity or production rate, which are related to fleet size. The PRICE algorithms are assumed to give fair coverage of the driving factors they address. PRICE uses weight, power, and similar physical parameters; R&M parameters; and an accounting of the production schedule.

SUPPORT EQUIPMENT

The specific causative agents and models applicable to this cost element are summarized in Table B.3.

Table B.3

SUPPORT EQUIPMENT COST DRIVERS

Driving Factor	Causative Agent	Applicable Models
Reliability & maintainability	Failure rates & modes	LSC-F
Physical characteristics	Aircraft size & weight design complexity	None
Maintenance concept	Type & amount of work at each maintenance level	LSC-F
Supply support concept	None	----
Training concept	Various training procedures	None
AGE concept	Constraints on type or number of AGE	LSC-F
Crew size & composition	No significant effect	----
Force size & activity rate	Aircraft maintenance workload	LSC-F
Basing/deployment concept	Number of operating sites	LSC-F
Mission type and profile	Operational reliability	None

Cause-Effect Relationships

The number of support equipment items needed depends on the aircraft maintenance workload, which is driven by aircraft failure rates. Force size and activity rate also drive the maintenance workload, through their effect on the total number of failures. The mission affects failure intervals, thereby modifying the workload. A large aircraft may allow the use of in-flight monitoring or test equipment that reduces the requirement for support equipment. The method of training maintenance personnel could affect the amount of AGE purchased for use in the training program. The quantity of support equipment should vary with number of potential wartime operating sites, since the utilization of support equipment is affected by the number of aircraft per site.

The types of support equipment required, as well as the quantities, are driven by maintenance concept decisions, such as those related to preventive maintenance.

Types and quantities are both directly driven by constraints or requirements imposed as support equipment policy decisions. The unit cost of an item of AGE may be related to its size, power, or other features potentially related to the size or weight of the aircraft. A large aircraft may require larger or more powerful (and therefore potentially more expensive) tractors, engine test cells, maintenance stands, etc., than a small aircraft. For a given size and weight aircraft, AGE requirements can be driven by the complexity of the aircraft design. An aircraft with many complex subsystems is likely to need support equipment of either greater complexity or diversity than an aircraft with simple subsystems. A change in crew size may mean a change in design that could affect the amount of aircraft maintenance required. For example, crew members can be traded against on-board equipment capable of performing the same functions. Such a change could affect AGE design, but the effect on support equipment cost is probably quite weak and is not considered in this analysis.

Applicable Models

LSC derives and costs quantities of peculiar support equipment items that are workload related, but the quantities are based on the assumption that an item of support equipment is available for a given maintenance action throughout the entire time period required to perform that action. Use of this assumption is, by itself, sufficient to keep the methodology from being rated as good. LSC provides sensitivity to R&M characteristics by relating support equipment requirements to hardware failure rates and to NRTS rates, which reflect the condition of the hardware following failure. Sensitivity to maintenance concept is provided through NRTS rates, which can take on values of 0.0 or 1.0 as a result of maintenance concept decisions. The support equipment concept is accounted for through a support equipment utilization rate and through the association, in the input data, of particular support equipment with particular FLUs. The specific support equipment to be used is a function of both the support equipment concept and aircraft requirements established by operational use. LSC uses total flying hours for a specific force size to drive the number of maintenance actions for which support equipment is required, although separate sensitivity to force size and activity rate is not provided. Sensitivity to basing and deployment concepts is limited. LSC accepts some support equipment parameters as base-level input, but all bases are assumed identical; and there is no consideration of the increase in the number of operating sites that results from wartime deployment. Common support equipment costs are included in LSC estimates of total support equipment cost, but they are input by the user, so the model provides no useful sensitivity for common support equipment. LSC is insensitive to physical characteristics, training practices, and the potential effect of mission type and profile on reliability.

TRAINING EQUIPMENT AND SERVICES

The estimation of initial training cost requires estimation of the cost of procuring training devices and the cost of providing initial training services. The specific causative agents and models applicable to this cost element are summarized in Table B.4.

Table B.4

TRAINING EQUIPMENT AND SERVICES COST DRIVERS

Driving Factor	Causative Agent	Applicable Models
Reliability & maintainability	None	----
Physical characteristics	Training equipment	None[a]
Maintenance concept	Types of work done in base maintenance	LSC-P
Supply support concept	None	----
Training concept	Training equipment characteristics	None[a]
AGE concept	None	----
Crew size & composition	Functions performed by crew	None
Force size & activity rate	Amount of training equipment	LSC-P
Basing/deployment concept	None	----
Mission type and profile	Functions performed by crew, training equipment characteristics	None

[a]Maintenance training equipment cost is provided to LSC as input data and is included in the model's output value of initial training costs.

Cause-Effect Relationships

Some physical characteristics, such as the types of material used, may have a significant effect on the design of training devices. Policy decisions about the types of maintenance work to be done at base level have a direct effect on the design of maintenance training devices and on the type of maintenance training required. Decisions about the type of training to be provided (general or specialized, formal or on-the-job) and about teaching techniques to be used in Air Force training have a direct effect on the design of training devices. Crew composition drives the types of training given to the initial crews and the design of training equipment. The amount of training equipment required may vary with the size of the force. Mission type (fighter, cargo, etc.) and profile should affect the content of the operator training program and therefore the cost of initial aircrew training and the cost of aircrew training devices.

Applicable Models

The LSC model is the only one evaluated that addresses this cost element. It computes an initial maintenance training cost by multiplying the number of maintenance personnel needed for the force by a cost/man factor generated by the contractor. The number of maintenance personnel is the only parameter, other than contractor input, to reflect weapon system characteristics. The use of total maintenance manpower results in a poor estimate of training services costs, since the contractor trains only the manpower needed for the first few operational units, not manpower for the entire force. Other than force size and activity date, the maintenance concept is the only driving factor that this methodology accounts for; and this is only to the extent that maintenance concept affects NRTS rates and repair times. The model's training cost estimate includes the cost of maintenance training equipment, but this must be estimated outside the model and input by the user; LSC contributes no useful estimating technique for training equipment cost. Neither LSC nor any of the other evaluated models estimates the cost of training the initial aircrews or the cost of equipment used in aircrew training.

DOCUMENTATION

The initial cost of documentation is determined by the amount or content of the material in the publications and by the number of copies needed. The specific causative agents and models applicable to this cost element are summarized in Table B.5.

Cause-Effect Relationships

The content or size of technical documentation is potentially determined by physical characteristics (structural material, design complexity), the AGE concept (number of types, complexity), crew composition (tasks performed by the crew), and the mission type and profile (number and complexity of mission related subsystems). The difficulty of accomplishing maintenance or servicing tasks, as influenced by R&M characteristics, could have a small effect. The number of copies of documentation required is determined by the maintenance concept (number of maintenance sites), training concept (number of classes, class size), and the basing and deployment concept (number of operating sites). Force size has an indirect effect, mainly through its influence on the number of maintenance and operating sites.

Applicable Models

The only generalized model to address the cost of documentation is the LSC model, which estimates only the acquisition cost of the original copy of technical publications needed for maintenance. Since reproduction and distribution costs are not considered, LSC provides no sensitivity to factors that drive the number of copies required. The model multiplies the number of original pages required by a fixed cost per page, so the only sensitivity provided is to changes in the number of pages of original maintenance documentation. This will vary with the causative agents listed above for physical characteristics, AGE concept, and mission type and

Table B.5

DOCUMENTATION COST DRIVERS

Driving Factor	Causative Agent	Applicable Models
Reliability & maintainability	No significant effect	----
Physical characteristics	Structural material, design complexity	None[a]
Maintenance concept	Number of maintenance sites	None
Supply support concept	None	----
Training concept	Number of classes	None
AGE concept	AGE quantity or complexity	None[a]
Crew size & composition	Functions performed by crew	None
Force size & activity rate	Number of maintenance and operating sites	None
Basing/deployment concept	Number of operating sites	None
Mission type and profile	Number & complexity of subsystems	None[a]

[a]The output of the LSC model can reflect this driving factor, but only through the input data. LSC itself does not model the cause-effect relationship.

profile; but the "number of pages" is an input that is independent, in the model, of all other variables. Hence, this category is essentially a throughput—with no directly modeled sensitivity to the driving factors.

INITIAL SPARES AND REPAIR PARTS

Models that address initial spares costs usually compute total inventory requirements to support a given level of operations, which in a sense represents "true" initial spares requirements. This contrasts with the official budgetary definition of initial spares—the spares required to support some initial period of operations (arbitrarily set at two years). Additional spares required to build up to inventory levels, but bought after this initial period, are purchased under the budget category "replenishment spares," which also covers spares purchases needed to replace condemned items. The models are evaluated here in terms of their ability to estimate the full initial inventory requirement, with the assumption that

the replenishment spares category represents true replenishment (replacement items). It is assumed that the model user can translate costs in these terms into budgetary categories outside the model. If the spares inventory buildup is properly time-phased, this should be a fairly straightforward task. With this proviso, the causative agents and models applicable to this cost element are as shown in Table B.6.

Table B.6

INITIAL SPARES AND REPAIR PARTS COST DRIVERS

Driving Factor	Causative Agent	Applicable Models
Reliability & maintainability	Failure rates, repair cycle times	LSC-F, MODMETRIC-F
Physical characteristics	Number of components, indenture structure commonality	LSC-P, MODMETRIC-F
Maintenance concept	Base repair capability	LSC-F, MODMETRIC-F
Supply support concept	Authorized stock levels, stock point locations	LSC-P, MODMETRIC-F
Training concept	None	----
AGE concept	None	----
Crew size & composition	None	----
Force size & activity rate	Total number of failures	LSC-F, MODMETRIC-F
Basing/deployment concept	Number of stock points, pipeline lengths	LSC-F, MODMETRIC-F
Mission type and profile	Operational reliability	None

Failure rates and repair cycle times affect the number of spares needed. Total spares cost will be driven by the number of items on an aircraft and their indenture structure. Commonality could affect the total amount of stock required for weapon systems using the common parts, since centralized inventories can be pooled. Base repair capability limits the rate at which failed items can be returned to serviceable condition, thus driving the rate at which demands for additional items will be received by the supply system. Authorized inventory levels, including safety stock, and stock point locations both drive the number of spares required. Both force size and activity rate affect the number of hardware failures that must be supported by the supply system. The number of stock points and pipeline lengths drive the

amount of stock needed for safety stock and for filling the resupply pipeline. Component failure intervals are known to be different for aircraft with different missions.

Applicable Models

MOD-METRIC uses a marginal analysis approach that is logically valid but that does not represent Air Force procedures for establishing stock levels. The model considers all components of a weapon system in a single analysis, relating their stock levels to a single measure of supply effectiveness. A similar procedure has recently been adopted for use in preparing Air Force spares budget requests, but spares procurement actions are based on individual item analyses. Although MOD-METRIC does not reproduce actual procurement decision processes, it does generate valid estimates of the cost effects of some driving factors. MOD-METRIC offers some sensitivity to R&M, physical characteristics, and maintenance and supply support concepts through the number of LRUs and the number of SRUs in each, repair times, NRTS rates, order and shipping times, and an expected backorder criterion. But the model represents demands with theoretical distributions based on parameters not always consistent with or derivable from actual Air Force experience. The NRTS rates and repair cycle times can reflect maintenance concept decisions, but only implicitly; there is no direct sensitivity to maintenance concept. These parameters are influenced by many things, including characteristics of the hardware, but the model does not provide a means of identifying or directly manipulating the contribution of maintenance concept. It does not address commonality, batch processing through depot repair, cannibalization, or lateral resupply. Results are based on the number of demands levied on the supply system, which reflects force size and activity rate but does not allow direct manipulation of them. MOD-METRIC provides some sensitivity to basing concept by allowing for the identification of Air Force bases with different order and shipping times, demand rates, repair times, and NRTS rates. But this sensitivity is rated only fair because these parameters must be derived outside the model. There is no provision for alternative mission effects.

LSC provides some sensitivity to R&M characteristics through "first line unit" (FLU) failure rates, NRTS rates, and repair cycle times. This sensitivity is considered only fair because of the lack of explicit coverage of "shop replaceable units" (SRUs). For the same reason, coverage of physical characteristics is poor, although the model is sensitive to the number of FLUs. Implicit accounting of repair of SRUs is consistent with the method used within AFLC to derive a repair cost for depot exchangeables, but this approach is not satisfactory for analyses in which the details of alternative designs are to be evaluated. Useful methodologies are driven by the output that is needed rather than by the form of the most conveniently obtained data. This model has only fair sensitivity to maintenance concept changes since it suffers from the same limitations in this area as MOD-METRIC.

LSC does not address the effects of batch processing through depot repair or cannibalization. Since spares demands are driven in the model by hardware failures, the effects of scheduled removals are not accounted for. The supply support concept is considered through an expected backorder criterion and order and shipping times. The same backorder criterion is used for all FLUs, with the result that the computed cost implications of some design differences are illogical. LSC ignores lateral resupply, depot safety stock, and all SRU spares. The computed inventory

is based on (force size) × (FH/month/AC), which is clearly sensitive to both force size and activity rate, although activity is measured only by flying hours. Estimates of cost changes due to changes in activity level are likely to be partially incorrect, since the effects of sortie length and rate, landing frequency, and other measures of activity are ignored. LSC allows for multiple bases, but provides only fair coverage of basing and deployment concept as a whole. Order and shipping time is the only variable that varies by base. The time input to the model is a weighted average of two values—one for CONUS bases and one for overseas bases. The model has no provisions for adjusting failure rates to reflect the effect of mission type.

SPARE ENGINES

The estimation of engine unit cost was discussed above as part of system investment cost estimation. Estimating the cost of spare engines is therefore essentially a matter of estimating the number of spare engines needed. The relevant causative agents and models are summarized in Table B.7. The causative agents shown here drive the "required" spare engines for the system, rather than the budgeted cost. In practice, amounts included in the budget for spare engines are

Table B.7

SPARE ENGINES COST DRIVERS

Driving Factor	Causative Agent	Applicable Models
Reliability & maintainability	Failure rates, repair & overhaul times	LSC-G MOD-METRIC-G
Physical characterisics	Number of engines per aircraft	LSC-G MOD-METRIC-G
Maintenance concept	Base repair capability, overhaul requirements	LSC-F MOD-METRIC-F
Supply support concept	Stock point locations, safety stock policies	LSC-F MOD-METRIC-F
Training concept	None	----
AGE concept	None	----
Crew size & composition	None	----
Force size & activity rate	Total number of failures	LSC-G MOD-METRIC-G
Basing/deployment concept	Number of stock points, pipeline lengths	LSC-F MOD-METRIC-F
Mission type and profile	Operational reliability	None

the result of a management decision process that takes into account a number of considerations, including a rule of thumb that says that the number of spare engines should be 20 to 25 percent of the number of installed engines (a rule that is not sensitive to any of the potential driving factors).

Cause-Effect Relationships

AFLC has computed the weapon system-driven engine requirement for conventional engines using an algorithm[2] similar to that used in LSC. MOD-METRIC has recently been used as an alternative method for determining requirements for modular engines. Estimates generated by these models are reasonable indications of the weapon system's influence on spare engine costs, although they should not be expected to replicate actual budget figures. MOD-METRIC is given a better rating for some driving factors than it received as an estimator of initial spares cost. This is because it has been accepted as a methodology for the official requirements determination process for modular engines.

Reliability and Maintainability. Engine failure rate drives the number of engines that are removed and that must be replaced through maintenance or from the supply system. Base and depot repair cycle times determine the rate at which serviceable engines can be obtained through repair. The difference is the rate at which demands for replacement engines will be sought from the stock of serviceable engines.

Physical Characteristics. The number of spare engines needed varies with the number of installed engines per airframe. Spare engine cost might vary with the number of other weapon systems that use the same engine, since centralized inventories can be pooled. However, this effect may not be significant if engines are managed separately for each weapon system or if simple percentage factors have strong influences on procurement decisions.

Maintenance Concept. Base repair capability drives repair times and the fraction of removed engines that are repaired at base level, thereby influencing the rate at which the maintenance system can generate serviceable engines. This drives the rate at which demands for engines are placed on the supply system. Overhaul policies affect both engine removal interval and depot repair cycle time.

Supply Support Concept. Stock point locations affect resupply pipeline lengths and the number of spare engines needed to fill the pipeline. Total spare engine quantities are dependent on the criteria used to establish the need for safety stock.

Force Size and Activity Rate. Both force size and engine activity rate affect the total number of engine removals that must be supported by the supply system.

Basing and Deployment Concept. The number of operating sites affects the number of local stock points. Operating site locations drive resupply pipeline lengths.

Mission Type and Profile. Component failure intervals are different for aircraft with different missions.

Applicable Models

MOD-METRIC has been used to set requirements for modular engines—re-

[2] See *Policy and Guidance*, AFM 400-1, Vol. I, June 21, 1976.

quirements for both whole engines and modules. Modular design leads to engine/module relationships analogous to the relationships between LRUs and SRUs in other aircraft subsystems. The model treats engines in the same way as other Initial Spares and Repair Parts, as described above. It provides more realistic representation of engines, however, because the marginal analysis approach has been accepted as one means of performing the official determination of initial engine requirements. The result is that coverage of reliability and maintainability and physical characteristics is good, since the model addresses all causative agents for these driving factors. Good capability is also provided for force size and activity rate, although the model does have two limitations that are not serious enough to limit its sensitivity significantly.

First, operating hours on each engine are assumed equal to the aircraft flying hours flown with the engine installed. This could cause the model to underestimate the number of spare engines required, since operating hours always exceed engine flying hours. It is possible to compensate for this by expressing the engine removal interval in flying hours rather than operating hours. Second, other parameters that can be considered measures of engine activity, such as thrust settings or throttle excursions, are not implicitly treated in the model. Less capability is provided for other driving factors. Since there is no direct sensitivity to maintenance concept, the model provides only fair coverage of this driving factor. Separate sensitivity to overhauls and unscheduled repair, for example, is not provided. Because there is no process in the model for adjusting these times to account for changes in stock point locations, sensitivity to supply support concept and basing and deployment concept is only fair.

LSC computes a spare engine cost using the number of average engine operating hours between removals, "pipeline" times (which include repair times), and the fraction of removed engines that are repaired at base level. These express the effects of R&M characteristics and, less directly, maintenance concept. Since there is no direct sensitivity to maintenance concept, the model provides only fair coverage of this driving factor. Separate sensitivity to overhauls and unscheduled repair is not provided. The model accounts for the number of engines installed in each airframe, which is the only physical characteristic that affects this cost element. It provides fair sensitivity to supply support concept by allowing the user to specify the desired probability of meeting a demand for a replacement engine. Sensitivity to changes in resupply pipeline lengths is not provided. LSC uses flying hours of the total force to reflect activity rate and force size. This gives good coverage of this driving factor, although the same limitations exist as are described for MOD-METRIC. LSC uses the number of stock points and therefore gives some effect of changing the basing structure, but it assumes that all bases are identical. Coverage of basing and deployment concept is therefore only fair. The effects of mission type and profile are not accounted for.

The algorithm used in LSC is similar to that used by AFLC to compute engine requirements for conventional (i.e., non-modular) engines. In practice, quantities of spare engines for new aircraft are not set in accordance with this procedure alone, but on other considerations as well. Estimates generated by LSC are reasonable indications of the weapon system's influence on spare engine requirements, but they will not necessarily replicate actual budget figures.

FACILITIES

The specific causative agents and models applicable to this cost element are summarized in Table B.8.

Table B.8

FACILITIES COST DRIVERS

Driving Factor	Causative Agent	Applicable Models
Reliability & maintainability	None	----
Physical characteristics	No significant effect	-----
Maintenance concept	Type & amount of work at each maintenance level	None[a]
Supply support concept	Number of stock points	None
Training concept	None	----
AGE concept	None	----
Crew size & composition	None	----
Force size & activity rate	None	----
Basing/deployment concept	Number of operating sites	LSC-P
Mission type and profile	None	----

[a]LSC output can reflect maintenance concept changes, but only if they can be accounted for through input values of the per-base cost of facilities.

Cause-Effect Relationships

Repair level decisions and policies regarding the work to be done at each maintenance echelon drive the number of sites at which maintenance facilities are needed, as well as the amount and type of facilities for each site. The number of stock points drives the number and size of material storage facilities. The number of operating sites determines the number of places at which facilities are required to support operations. The facilities needed at each base may change as the number of bases changes. The construction of facilities could vary from base to base because of differences in existing facilities and the requirements of other weapon systems operating from the same bases.

No effect of R&M is foreseen; maintenance facilities are largely fixed by the need to perform maintenance, not by variations in maintenance workloads. Ex-

treme variations in physical characteristics, such as extraordinary aircraft size, may have some significance, but there is no general effect.

Applicable Models

LSC multiplies the cost of maintenance and operating facilities for a single base by the number of bases. This provides some sensitivity to the basing and deployment concept but ignores the fact that different bases usually require different facilities. The model has no means of estimating the facilities cost of an individual base, so its sensitivity is poor at best. None of the evaluated models addresses material storage facility costs specifically.

WAR RESERVE MATERIAL

Causative agents peculiar to WRM and applicable models are shown in Table B.9.

Table B.9

WAR RESERVE MATERIAL COST DRIVERS

Driving Factor	Causative Agent	Applicable Models
Reliability & maintainability	Failure rates, repair cycle times	MODMETRIC-F
Physical characteristics	Number of components, indenture structure, commonality	MODMETRIC-F
Maintenance concept	Base repair capability	MODMETRIC-P
Supply support concept	Authorized stock levels stock point locations, WRM requirements	MODMETRIC-P
Training concept	None	----
AGE concept	None	----
Crew size & composition	None	----
Force size & activity rate	Total number of failures, wartime sortie rate	MODMETRIC-F
Basing/deployment concept	Pipeline lengths, number of stock points	MODMETRIC-F
Mission type and profile	Operational reliability, type and number of munitions	None

Cause-Effect Relationships

The decision to establish a separate WRM requirement for spares is a part of a supply support concept. Force size and wartime sortie rate drive the total requirement for WRM munitions, missiles, and other operations-related items as well as the WRM spares requirement. The type and quantity of WRM munitions, missiles, and related items needed for wartime operations varies with mission type and profile, as do component failure rates and the quantity of WRM spares needed.

Applicable Models

The models do not address WRM requirements specifically; WRM spares are the only WRM items even indirectly considered. MOD-METRIC will compute an inventory including base level self-sufficiency spares if the input describes a wartime environment. War readiness spares kits (WRSKs) would not be accurately estimated by this method because they are based on operations without resupply—a situation the model does not handle. The MOD-METRIC discussion for Initial Spares also applies to WRM spares, although the model's coverage of maintenance concept and supply support concept is rated lower here because it does not model the concepts from which the Air Force derives its WRSK requirements. Mission effects are not addressed.

AIRCREWS

The specific causative agents and models applicable to this cost element are summarized in Table B.10.

Cause-Effect Relationships

Proficiency training policies limit the crew ratio—the number of crews cannot be so large that their total required proficiency flying exceeds the flying hours that can be achieved with available aircraft. Crew size directly affects the total number of aircrew members associated with a force of a given size. The number of crews required increases with force size and with the expected wartime activity rate, but cannot exceed the number that can maintain proficiency with the number of peacetime flying hours available. The number of crews is influenced by the standby alert time required. Mission effects are accounted for by the specified crew size and composition.

Applicable Models

BACE and CACE output total PPE manpower cost; the portion attributable to aircrews can be estimated from force size and crew size data input to CACE. The pay costs used do not differentiate between aircrew and non-aircrew personnel, but differentiated costs are published in AFR 173-10 and could be applied with slight changes to the models. This would produce estimates with good sensitivity to crew size and composition. Force size is a stronger driver than activity rate, and the models' coverage is good because it accounts well for force size. Aircrew costs

Table B.10

AIRCREWS COST DRIVERS

Driving Factor	Causative Agent	Applicable Models
Reliability & maintainability	None	----
Physical characteristics	None	----
Maintenance concept	None	----
Supply support concept	None	----
Training concept	Proficiency training	None
AGE concept	None	----
Crew size & composition	Crew size	BACE/CACE-G
Force size & activity rate	Force size, wartime and peacetime activity rates	BACE/CACE-G
Basing/deployment concept	Standby alert time	None
Mission type and profile	No direct effect	-----

should vary linearly with force size, and the cost estimated by BACE or CACE for a single squadron can be multiplied by the number of squadrons corresponding to the force size of interest. The models do not address the other driving factors.

COMMAND STAFF

The specific causative agents and models applicable to this cost element are summarized in Table B.11.

Cause-Effect Relationships

Some command staff functions may be related closely enough to flying operations to be driven by force size or activity rate. Flight safety (FC 1061) is an example. Command staff functions must often be performed at each base or squadron. The number of personnel needed to perform these functions may depend on how the squadrons are distributed to operating bases. Command staff functions closely related to flight operations may have manpower requirements that vary

Table B.11

COMMAND STAFF COST DRIVERS

Driving Factor	Causative Agent	Applicable Models
Reliability & maintainability	None	----
Physical characteristics	None	----
Maintenance concept	None	----
Supply support concept	None	----
Training concept	None	----
AGE concept	None	----
Crew size & composition	None	----
Force size & activity rate	Flying hours, number of wings/squadrons	BACE/CACE-F AFM 26-3-F
Basing/deployment concept	Organizational structure, number of deployed operating sites	AFM 26-3-F
Mission type and profile	Mission type	AFM 26-3-F

with mission. Some mission types could, for example, be more dangerous than others, with a correspondingly greater need for flight safety manpower.

Applicable Models

AFM 26-3 provides a simple methodology relating flight safety (FC 1061) manpower for a base to flying hours and mission type. Because this method does not address other command staff functions, its coverage is classified as fair. BACE and CACE allow total manpower for a squadron to be multiplied (outside the model) by the number of squadrons. The AFR 173-10 PPE manpower table shows manpower associated with wing/base staff, which includes command staff; but no methodology is presented for estimating manpower for new weapon systems or alternative basing concepts. The sensitivity of BACE and CACE is therefore only fair.

POL

The specific causative agents and models applicable to this cost element are summarized in Table B.12.

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Table B.12

POL COST DRIVERS

Driving Factor	Causative Agent	Applicable Models
Reliability & maintainability	Engine failure rate	None
Physical characteristics	Engine type and number per aircraft, aerodynamics	LSC-F
Maintenance concept	Engine maintenance policies	None
Supply support concept	None	----
Training concept	Proficiency flying hour rate, use of simulators	BACE/CACE-F,
AGE concept	None	----
Crew size & composition	None	----
Force size & activity rate	Engine operating hours	BACE/CACE-F, LSC-F
Basing/deployment concept	No significant effect	----
Mission type and profile	Fuel consumption rate	LSC-F

Cause-Effect Relationships

The engine failure rate affects the amount of POL consumed during engine operating time associated with maintenance. Fuel consumption will vary with the number of engines per aircraft and with other aircraft and engine characteristics, such as airframe drag and engine installation. POL consumed during engine operation associated with maintenance is affected by inspection and overhaul policies that drive the amount of engine maintenance performed. Proficiency requirements for aircrews and policies on the use of simulators affect flying hours and thus POL cost. The total POL consumption is driven by the size of the fleet of aircraft. Deployment concept can affect POL consumption (e.g., POL requirements for flying to deployment sites), but this effect is assumed to be accounted for by the specified activity rate. Fuel consumption is driven by the engine operating conditions encountered during flight, which may vary with mission profile.

Applicable Models

BACE and CACE estimate POL cost using a cost per flying hour factor. The periodic updates to AFR 173-10 show substantial variations in the POL consumption rates (gallons per flying hour) for current aircraft, suggesting that driving

factors other than flying hours can affect the rates considerably. Although no explanation of the variations is supplied, their existence indicates that the usefulness of the BACE and CACE factors is limited. These models are therefore rated only fair. The model can be considered partly sensitive to training concept, to the extent that aircrew training requirements are reflected in input flying hour rates.

LSC uses flying hours and number of aircraft as direct multipliers of fuel consumption per flying hour. The validity of this relationship is constrained mainly by the quality of fuel consumption rate information—a parameter mainly determined in LSC by the number and type of engines. This equation provides only fair coverage of the cause-effect relationship, however, because consumption rates per flying hour provide only indirect sensitivity to changes in POL used on the ground, as during maintenance. Airframe drag and other physical characteristics that may affect POL consumption are not treated directly. None of the generalized models gives direct sensitivity to mission effects, but the fuel consumption rate used in LSC is presumably based on some specific mission profile or set of profiles and therefore gives limited or fair sensitivity.

Engine operating time that occurs during maintenance is not dealt with explicitly in the models, although it can be a significant fraction of total engine operating hours.

SECURITY

The specific causative agents and models applicable to this cost element are summarized in Table B.13.

Cause-Effect Relationships

The number of Air Police for aerospace system security varies with force size (or with number of squadrons) and the number of aircraft in a squadron. Security requirements are greater for units that are based overseas or that deploy overseas. The weapons load to be protected affects the size of the security force required: nuclear munitions need more protection than non-nuclear munitions.[3] There may be a minimum security force size per squadron or per base.

Applicable Models

BACE and CACE allow total manpower cost for a squadron to be multiplied (outside the model) by the number of squadrons. This provides fair sensitivity to force size, since the model results can be scaled up for any number of squadrons. AFR 173-10 PPE manpower table shows typical squadron manpower associated with aerospace system security, but this method's usefulness is constrained by the fact that no technique is presented for estimating security manpower for new weapon systems. AFM 26-3 refers to the existence of manpower standards for security, but these were not available for evaluation. The evaluated models are not sensitive to deployment policy or weapons load.

[3] Air Force Test and Evaluation Center, *Cost of Ownership Handbook*, Kirtland Air Force Base, New Mexico, p. 4-11.

Table B.13

SECURITY COST DRIVERS

Driving Factor	Causative Agent	Applicable Models
Reliability & maintainability	None	----
Physical characteristics	None	----
Maintenance concept	None	----
Supply support concept	None	----
Training concept	None	----
AGE concept	None	----
Crew size & composition	None	----
Force size & activity rate	Number of aircraft or squadrons	BACE/CACE-F
Basing/deployment concept	Number of aircraft per operating site	None
Mission type and profile	Weapons load	None

OTHER DEPLOYED MANPOWER

The specific causative agents and models applicable to this cost element are summarized in Table B.14.

Cause-Effect Relationships

Because the functions that make up this category are not currently well defined and may be situation specific, it cannot be evaluated completely. Some information, however, is available. AFM 26-3 indicates that Information (FC 1040) manpower, a function that should be covered in this category, is related to base population and location and to mission type. Many categories of personnel are associated with functions that must be performed at each operating site or for each operating unit and are therefore affected by force size and by basing and deployment policies. In addition to its effect on Information manpower, the mission type can drive the manpower for functions related to unique aspects of various missions, such as photographic interpretation in reconnaissance units.

Table B.14

OTHER DEPLOYED MANPOWER COST DRIVERS

Driving Factor	Causative Agent	Applicable Models
Reliability & maintainability	None	----
Physical characteristics	None	----
Maintenance concept	None	----
Supply support concept	None	----
Training concept	None	----
AGE concept	None	----
Crew size & composition	None	----
Force size & activity rate	Number of wings/squadrons	BACE/CACE-F AFM 26-3-F
Basing/deployment concept	Number of operating sites, base population and location	AFM 26-3-F
Mission type and profile	Mission type	None

Applicable Models

BACE and CACE provide sensitivity to force size in that they compute the total manpower cost for a squadron, which can be multiplied (outside the model) by the number of squadrons. The AFR 173-10 PPE manpower table shows manpower associated with wing/base staff, which includes Other Deployed Manpower, but no methodology is presented for estimating manpower for new weapon systems.

AFM 26-3 relates Information manpower (FC 104X) to base population and indicates that CONUS and overseas bases have different requirements. Manpower standards are presented for CONUS bases, driven by base population and location of the base with respect to metropolitan areas. Although sensitivity to mission is not provided and no standards for overseas bases are given, the standards that are included give fair coverage of force size and basing and deployment concepts. Since this method does not address other command staff functions, its coverage is classified as fair.

The evaluated methodologies do not specifically address requirements of individual missions.

DEPLOYED UNIT MISCELLANEOUS O&M (PERSONNEL SUPPORT)

Cause-Effect Relationships

Previous studies of "BOS" costs similar to those that constitute Miscellaneous O&M have concluded that the BOS costs are related to number of personnel supported and to the area of improved facilities. For this study, therefore, it is assumed that Miscellaneous O&M cost is related to the number of personnel supported and to the area of the facilities they occupy. Potential driving factors include the facility area and, indirectly, the factors that drive manpower. This identification of driving factors is less rigorous than one would like; further study of this cost element and possible cause-effect relationships is called for in order to discover the true driving factors.

Applicable Models

The BACE model computes a "Miscellaneous Support" cost per PPE military man, part of which is allocated to the operating squadron. This cost presumably contains much the same items as Miscellaneous Operations and Maintenance. BACE therefore offers an indirect sensitivity to the factors that drive manpower. Deployed unit manpower is affected by five driving factor categories: (1) training concept, (2) crew size and composition, (3) force size and activity rate, (4) basing and deployment concept, and (5) mission type and profile. BACE addresses the effects of crew size and force size by relating cost to total manpower, which is driven by these factors. BACE documentation in AFR 173-10 does not define Miscellaneous Support or explain the derivation of the cost-per-man factors it presents. The factors are arbitrary conventions and may or may not be reasonable approximations of the cost that might be incurred for a new aircraft. The amount of money involved is comparatively small, but the model underestimates the costs attributed to most aircraft PPEs in the F&FP, so its coverage is considered poor.

AIRCRAFT MAINTENANCE MANPOWER

The specific causative agents and models applicable to this cost element are summarized in Table B.15.

Cause-Effect Relationships

Reliability and Maintainability. Aircraft failure rates and required repair times and team sizes affect the aircraft maintenance workload, which drives both the number of men required for aircraft maintenance and the required support equipment inventory, which in turn affects the number of men needed for support equipment maintenance.

Physical Characteristics. Aircraft size, number of components, and general design features may affect the number of aircraft maintenance men required. The number of engines is a factor in determining the manpower needed in the propulsion shop. Support equipment maintenance requirements may be related to support

Table B.15

AIRCRAFT MAINTENANCE MANPOWER COST DRIVERS

Driving Factor	Causative Agent	Applicable Models
Reliability & maintainability	Failure rates, repair times, team sizes, etc.	LSC-F LCOM-F
Physical characteristics	Aircraft weight, size, number of components	LSC-F LCOM-F
Maintenance concept	Amount & types of work done in base level maint.	LSC-P LCOM-F
Supply support concept	Authorized stock levels	LCOM-F
Training concept	OJT, cross training, amount & type of training equipment	LCOM-P
AGE concept	Work accomplished using AGE	LSC-P LCOM-F AFM 26-3-F
Crew size & composition	No significant effect	----
Force size & activity rate	Maintenance workload	BACE/CACE-F LSC-F AFM 26-3-F
Basing/deployment concept	Number of operating sites, ground alerts	LCOM-F
Mission type and profile	Operational reliability	LCOM-F

equipment size, power, or other features potentially related to the weight, size, and other physical characteristics of the aircraft.

Maintenance Concept. The amount and types of work to be done at base level affect the number of aircraft maintenance men required. There is also an effect on the number and types of support equipment required, with a resulting effect on support equipment maintenance manpower. Decisions on amount and type of maintenance work to be done at base level also have an effect on the type of maintenance training required and, therefore, on the training devices required; but the effect on training device maintenance manpower should be small.

Supply Support Concept. The level of supply support provided (stock levels) drives the amount of maintenance work needed to maintain a given level of system capability.

Training Concept. The amount of OJT provided, the amount of cross-training, etc., affect the total requirement for maintenance manpower. The amount and type of training equipment used, and hence its maintenance cost, are directly related to the training concept applied.

AGE Concept. There may be a tradeoff between support equipment quantity and features and the amount of aircraft manpower required to diagnose and correct failures and to perform scheduled maintenance or general support tasks. There is a direct effect on support equipment maintenance requirements.

Crew Size and Composition. For a given size and weight vehicle, a change in crew size or composition means a change in design that could affect the amount of aircraft maintenance required, but the effect on maintenance manpower is likely to be small.

Force Size and Activity Rate. Both force size and activity rate affect aircraft maintenance workload, which drives aircraft maintenance manpower. The only effect on support equipment maintenance manpower is through support equipment quantity, which is estimated as part of investment cost calculations.

Basing and Deployment Concept. The number of potential operating sites drives the number of aircraft maintenance men required to operate in a wartime scenario. Ground alert imposes a different maintenance requirement than exists for operations without alerts. The only effect on support equipment manpower is through support equipment quantity, which is generally modeled as part of the estimation of support equipment investment cost.

Mission Type and Profile. The mission affects aircraft failure intervals, which significantly affect workload, which, in turn, drives the aircraft and support equipment maintenance manpower requirements.

Applicable Models

BACE and CACE generate PPE manpower cost for a squadron with a specified number of aircraft. Maintenance manpower is an input to the models, and no technique is given in the AFR 173-10 documentation for the estimation of maintenance manpower for new aircraft. Maintenance man-hour-per-flying-hour (mmh/fh) figures are provided in the regulation for current aircraft, but the regulation provides no explanation of how the figures are used to revise maintenance manpower with changes in flying hour rates. The fair rating for these models for force size and activity rate is based on their estimation of squadron costs, which can be multiplied by the number of squadrons in the force.

LSC computes the effect of R&M on direct labor required for a specified number of engines and FLUs, but gives only fair sensitivity because it does not cost actual manpower. It offers some sensitivity for aircraft maintenance manpower through NRTS, failure rates, man-hours per repair, etc. These reflect R&M characteristics and, to a lesser extent, maintenance concept. These parameters reflect maintenance concept changes only implicitly, so only poor sensitivity to the cause-effect relationships is provided. Physical characteristics are accounted for through the use of the number of engines and number of FLUs, but the model's sensitivity is limited because it does not explicitly treat SRU repair. Although LSC does not generate AGE maintenance manpower, it does model AGE maintenance and operating costs as a fraction of procurement cost; this approach may reflect some effects of size, power, or other physical characteristics, AGE concept decisions, and the indirect effect of aircraft maintenance concept decisions. AGE concept sensitivity is poor, since it is at best implicit. For both aircraft and AGE maintenance, total force flying hours, used as a substitute for the true failure mechanism (such as sorties, operating hours, etc.) provides sensitivity to force size and activity rate.

LCOM models quite realistically the manpower required for aircraft maintenance and general support tasks that affect sortie capability, but requires modification for use with some unconventional maintenance concepts. LCOM computes realistic variations of aircraft manpower with R&M, for most maintenance concepts. The detailed task and hardware breakdowns it uses provide direct sensitivity to physical characteristics and mission type and profile; but for the most part, only tasks that affect sortie capability are modeled. LCOM can evaluate the effects of changes in stock levels on aircraft maintenance manpower requirements and thus is sensitive to some aspects of the supply support concept. LCOM accounts for the structure of the base maintenance organization, associating different groups of maintenance personnel with different functions or different hardware. Thus workers can be grouped on the basis of the systems they are trained to work on, and differences in the use of OJT or cross-training can be reflected. But since the approach is not straightforward, this capability is rated poor.

Sensitivity of aircraft maintenance manpower to AGE concept is provided by LCOM if task requirements for support equipment and manpower are available. LCOM analyses of aircraft maintenance manpower provide sensitivity to basing and deployment concept through the use of different size units encountered with deployed forces. LCOM can use failure rates expressed in terms of a number of different activities or time units (e.g., sorties, landings, or operating hours to reflect activity rate effects), but it does not automatically modify those rates to correspond to changes in the level of flight operations. An LCOM run can address more than one mission profile, but failure rates are not automatically adjusted to make them valid for new sortie lengths.

For most aircraft maintenance work centers, AFM 26-3 provides a manpower standard based on man-hour-per-flying-hour factors derived from data reported in the Maintenance Data Collection System. These constitute a methodology for generating manpower estimates that vary with flight activity. Since the factors are derived directly from historical data, they are available only for existing aircraft and are strictly valid only under the conditions that existed at the time the data were collected. The effects of significant changes in activity rate, or other variables, cannot be correctly predicted using these factors. AFM 26-3 manpower standards for the survival equipment maintenance shop (FC 2315) and the AGE maintenance shop (FC 2340) are based on direct workload; i.e., the amount of direct labor required. Using these standards as part of a model would require modeling the maintenance of this equipment in addition to the maintenance of the aircraft. No generalized models address maintenance at this level, so these standards are of little use for systems for which workload levels are not already established. The precision measuring equipment (PME) laboratory manpower standard in AFM 26-3 is based on the number of PME items in the local inventory. This standard is useful only when AGE concept changes can be translated by some means into PME item quantities. This methodology is rated fair because it is useful but incomplete; it does not cover all of aircraft maintenance.

Training equipment maintenance is not considered by any of the evaluated models.

ORDNANCE MAINTENANCE MANPOWER

The specific causative agents and models applicable to this cost element are summarized in Table B.16.

Table B.16

ORDNANCE MAINTENANCE MANPOWER COST DRIVERS

Driving Factor	Causative Agent	Applicable Models
Reliability & maintainability	None	----
Physical characteristics	Stores stations	LCOM-F
Maintenance concept	None	----
Supply support concept	None	----
Training concept	OJT, cross training	None
AGE concept	Munitions functions accomplished using SE	LCOM-F
Crew size & composition	None	----
Force size & activity rate	Total FH & sorties,munitions workload	BACE/CACE-F LCOM-F AFM 26-3-F
Basing/deployment concept	Number of operating sites	LCOM-F
Mission type and profile	Number & type of munitions	LCOM-F AFM 26-3-F

Cause-Effect Relationships

The number of munitions maintenance personnel is affected by general physical features, such as whether stores are carried externally or in an internal bay. Training practices such as the amount of OJT provided or the use of cross-training can affect the total number of personnel needed to provide a given level of capability. Force size and activity rate affect the munitions maintenance workload, which drives related manpower. The number of potential operating sites drives the number of munitions maintenance men required, if only because manpower must be assigned in integral numbers of crews. The mission drives the munitions manpower because it determines the numbers and types of munitions and guns to be supported.

Applicable Models

BACE and CACE generate PPE manpower cost for a squadron with a specified number of aircraft flying a given number of hours. Maintenance manpower is an input to the models, and no techniques are suggested in the AFR 173-10 documentation for the estimation of ordnance maintenance manpower for new aircraft.

LCOM can model sortie-related munitions functions, such as weapons loading, although it would require some modification before it could address some unconventional maintenance concepts. This provides sensitivity to physical location and number of stores stations and, through the number and type of munitions loaded, to mission type.

LCOM can address interactions between munitions manpower and support equipment if data are available on the functions to be accomplished using support equipment and those to be done by manpower alone. LCOM can readily address the effects of force size and activity rate because these are basic elements of the operating scenario that is needed to apply the model. LCOM analyses of aircraft maintenance manpower have accounted for the different size units encountered with deployed forces. These effects could also be addressed for sortie-related munitions manpower.

AFM 26-3 standards for munitions services manpower provide sensitivity to force size and activity rate and to mission type and profile by relating the number of men needed to the number and type of aircraft supported and to their mission. The standards for munitions maintenance and storage are also sensitive to mission type and profile in that they relate manpower to the total weight of the munitions assigned to the unit, which will vary with mission. The usefulness of these standards is constrained for all driving factor categories by the lack of a technique for developing standards for new aircraft. There are also a few manpower categories in munitions maintenance for which AFM 26-3 does not provide standards.

MAINTENANCE MATERIAL

The specific causative agents and models applicable to this cost element are summarized in Table B.17.

Cause-Effect Relationships

The amount of material required is driven by the number of maintenance actions, which depends on the number of components, component failure rates, the number of aircraft in the force, and the level of activity. The mission also affects failure rates. Policy decisions on the amount and type of work to be done at base level have a direct effect on the amount of material used. For a given size and weight vehicle, a change in crew size means a change in design that could affect the amount of maintenance required, but the effect on material is likely to be too small to be worth considering in generalized models. Although policies on safety stock levels, reorder quantities, and distribution rules have a direct effect on the amount of stock held in inventory, they should have little or no effect on the amount of material consumed in aircraft maintenance.

Table B.17

MAINTENANCE MATERIAL COST DRIVERS

Driving Factor	Causative Agent	Applicable Models
Reliability & maintainability	Failure rates	LSC-P
Physical characteristics	Number of aircraft components	LSC-P
Maintenance concept	Amount & types of work in base level maintenance	LSC-P
Supply support concept	No direct effect	----
Training concept	None	----
AGE concept	None	----
Crew size & composition	No significant effect	----
Force size & activity rate	Number of FH, sorties, UE	BACE/CACE-F LSC-F
Basing/deployment concept	None	----
Mission type and profile	Operational reliability	None

Applicable Models

BACE and CACE provide cost estimates that vary in reasonable fashion with force size and flying hour changes, although the factors (for current aircraft only) are not consistent with F&FP figures. BACE uses cost/FH factors only, and CACE uses a combination of cost/FH and (for a few aircraft) cost/UE factors. Some of the CACE factors were developed by PACAF, SAC, and TAC for aircraft operated by them. The methodology developed by these commands estimates Base Maintenance Material cost as a function of flying hours, number of installations, and (for TAC only) number of UE. No methodology is provided for estimating appropriate factors for new aircraft. The amounts generated by BACE factors for most current aircraft underestimate the corresponding PPE figures in the F&FP.

The LSC model computes a material cost for repair of FLUs, but without explicit treatment of consumable material. Some sensitivity to R&M characteristics and maintenance concept is provided through NRTS, manhours/repair, etc.; but material cost is calculated as a cost per labor hour. This is consistent with practices used to set hourly cost rates at the Air Logistics Centers, but it is only an approximation of the true relationship between material and labor. This approximation is likely to be more nearly correct in some instances than in others. One can conceive

of design maintenance concept changes that would involve tradeoffs between labor and material—increasing one while decreasing the other. The effects of changes in type of malfunction, failure mode, and condition after failure are not directly modeled. The model accounts for the number of FLUs by addressing each individually. SRU repair is not treated explicitly. LSC costs are based on a total number of flying hours for a given force size, using total flying hours to drive FLU failures. Where failures are not directly related to flying hours (i.e., they are sortie or operating-hour related), misleading results can be obtained from varying flying hours without appropriate changes in input MTBF.

BELOW DEPOT MAINTENANCE MISCELLANEOUS O&M (PERSONNEL SUPPORT)

Cause-Effect Relationships

Previous studies of "BOS" costs similar to those that constitute Miscellaneous O&M have concluded that the BOS costs are related to number of personnel supported and to the area of improved facilities. For this study, therefore, it is assumed that Miscellaneous O&M cost is related to the number of personnel supported and to the area of the facilities they occupy. Potential driving factors include the facility area and, indirectly, the factors that drive manpower. This identification of driving factors is less rigorous than one would like; further study of this cost element and possible cause-effect relationships is called for in order to discover the true driving factors.

Applicable Models

The BACE model computes a Miscellaneous Support cost per PPE military man, which presumably contains many of the same items as Miscellaneous Operations and Maintenance. BACE therefore offers an indirect sensitivity to the factors that drive base level maintenance manpower, which includes all driving factor categories except crew size and composition. The only driving factor that can be manipulated using BACE is the force size. There is no direct connection in the model between this factor and the maintenance manpower used. The number of squadrons implied by a given force size can, however, be multiplied by the model's estimate of the cost for a single squadron. BACE documentation in AFR 173-10 does not define Miscellaneous Support or explain the derivation of the cost/man factors it presents. The factors are arbitrary conventions and may not be reasonable approximations of the costs that might be incurred for a new aircraft. Although the magnitude of this cost is comparatively small, the model underestimates the corresponding cost attributed to most current aircraft PPEs in the F&FP. The sensitivity can only be classified as poor.

INSTALLATIONS SUPPORT

Cause-Effect Relationships

Previous studies have shown Installation Support cost to be related to the number of personnel supported and to the area of improved facilities. Potential driving factors are the facility area and, indirectly, the factors that drive manpower.

Applicable Models

BACE and CACE both estimate costs for Base Operating Support and Real Property Maintenance (which together constitute the major part of the Installations Support category). BACE generates costs for BOS/RPM military pay, BOS/RPM civilian pay, and a category called "BOS Miscellaneous Support." The same manpower and pay calculations are used in CACE (although the cost categories are organized differently), but the equivalent of Miscellaneous Support cost (called BOS/RPM Non-pay Support) is based on different factors. AFR 173-10 does not define the coverage of either of the cost/man figures for miscellaneous support. We believe the BACE factor to be an arbitrary convention. The CACE factors were derived from a study of non-pay BOS and RPM costs conducted in 1972 (in which Rand participated), updated to current dollars by official OSD price deflators. The BOS/RPM manpower calculation process in AFR 173-10 is empirical and not sensitive to the driving factors. Nevertheless, these models offer an indirect sensitivity to those driving factor categories that can affect Deployed Unit Manpower and Below Depot Maintenance Manpower. The driving factors that can be manipulated using these models are crew size (in the models) and force size (as an external multiplier of model results for a single squadron). The sensitivity to these cost factors gives enough capability to merit rating these models as providing fair coverage of Installations Support cost. Sensitivity to facility area is not provided.

Although LSC does not address Installations Support cost per se, it includes "base level supply management" and "transportation" cost estimates that in part overlap some Installations Support functions. These costs are based on "standard" Air Force cost factors, but the model documentation gives no basis for the recommended values. Because model results are difficult to relate to the relevant budgeting and programming categories, validation of the model through comparison with actual costs is not feasible.

In LSC, the cost of base level management of aircraft item inventory is estimated on a cost-per-line-item basis (but only for items new to the base level supply system); thus it is sensitive to the number of (new) items in the aircraft. This approach ignores the cost of managing items that are not new to the base supply system, and, at best, it provides weak sensitivity of an indeterminate part of Installations Support cost to physical characteristics of the aircraft system.

The LSC model computes a transportation cost that is described as including "packing, shipping, and transportation" for items shipped from base to depot or depot to base. This cost is a function of the number of failed items shipped to the depot for repair or replacement, using a cost-per-pound factor. This number of items is derived from input related to R&M, maintenance concept, and force size and activity rate. Nominally, these costs overlap the Installations Support, Materi-

al Distribution, and Second Destination Transportation categories. The factor used does not separate these components. The relationship to the Installations Support category is particularly weak and probably accounts for a relatively small portion of the costs attributable to the system.

DEPOT MAINTENANCE MANPOWER

The specific causative agents and models applicable to this cost element are summarized in Table B.18.

Table B.18

DEPOT MAINTENANCE MANPOWER COST DRIVERS

Driving Factor	Causative Agent	Applicable Models
Reliability & maintainability	Failure rates & modes, repair cycle times	LSC-F
Physical characteristics	Aircraft size and number of components	LSC-P DMCE-P[a]
Maintenance concept	Types and amount of work done in depot maintenance	LSC-P
Supply support concept	Authorized stock levels	None
Training concept	None	----
AGE concept	AGE functions & quantity	None
Crew size & composition	No significant effect	----
Force size & activity rate	Total number of failures	BACE/CACE-F DMCE-F LSC-F
Basing/deployment concept	None	----
Mission type and profile	Operational reliability	DMCE-P

[a]"DMCE" identifies the AFLC Depot Maintenance Cost Equations.

Cause-Effect Relationships

Failure rates, failure modes, and repair times drive the number of men required. Failure rates are known to vary by mission. The severity of failure may also vary by mission. The total number of failures is influenced by force size and activity rate. Changes in aircraft size, number of components, or general design features

can affect the number of components that are subject to failure or the amount of labor required per failure. Maintenance policies, such as repair level decisions, have a strong effect on the amount and types of work done at depot level. For a given size and weight vehicle, a change in crew size means a change in design that could affect the amount of maintenance required, but this would not have significant effect on depot maintenance costs. The level of supply support provided (stock levels) drives the amount of maintenance work needed to maintain a given level of organizational capability. There may be a tradeoff between support equipment quantity and features and the amount of manpower required to diagnose and correct failures.

Applicable Models

BACE and CACE use cost/UE and cost/FH factors to compute total depot maintenance costs. Manpower and material costs are not separated. The factors are based on historical weapon system-level depot cost data. The division between costs attributed to flying hour variations and those attributed to inventory (UE) variations is theoretical (and has not been empirically verified). The cost data used to generate the factor values include costs of "common" items (used on more than one type of aircraft) that are allocated to systems on the basis of a rule of thumb. They apply only at the total system level and to current aircraft and selected aircraft currently in development or production. These factors provide rough measures of the cost of current systems under current (and past) conditions, but they are a weak basis for estimates for new aircraft or new operating and support concepts.

LSC computes a cost for depot direct maintenance labor for FLUs. Engine overhaul cost is also computed; but as a total, not differentiated between manpower and material. The model provides some sensitivity through MTBF, NRTS, man-hours/repair, condemnation rates, engine removal rates, and the numbers of FLUs and engines. These parameters are related closely enough to the aircraft to provide fair sensitivity to R&M characteristics. The number of components is the only physical characteristic to which the model is sensitive; sensitivity to weight, volume, and other physical characteristics is not provided. The maintenance concept is considered implicitly through parameters such as NRTS rate, but this does not allow straightforward evaluation of concept changes. LSC does not address depot maintenance of SRUs or whole aircraft. The computed cost is based on a total number of flying hours for a given force size, using flying hours to drive FLU failures and engine removals; misleading results can be obtained by varying flying hours without appropriate changes in input values of MTBF, where true failures are driven by sorties, operating hours, or other mechanisms.

The depot maintenance cost equations in AFLCP 173-4 are the result of a statistical analysis of the effects of physical characteristics on aircraft and engine depot maintenance costs. Weight, speed, and thrust are included as useful variables. Other driving factors the equations address are force size and activity rate and mission type and profile. Some of the equations accept activity rate as an input, but the documentation acknowledges that the true effect of activity rate is unknown.[4] AFLCP 173-4 has different equations for fighter, cargo, trainer, and hel-

[4] AFLCP 173-4, p. 1.

copter aircraft. The derivation of different equations is an attempt to account for the effects of mission differences without specifically modeling the cause-effect relationships. The cost data used to develop the equations were derived in part by allocating engine overhaul and accessory repair costs to using aircraft. These allocation processes are sources of error that cannot be avoided, since available depot data do not relate these costs directly to mission/design/series. Because of this data problem, as well as the limitations already noted, this methodology provides poor estimating capability for these effects. Its sensitivity to force size and activity rate is fair, because the equations are structured to estimate cost per aircraft, and a linear relationship between cost and force size is reasonable.

DEPOT MAINTENANCE MATERIAL

Depot maintenance material cost is driven by much the same factors as depot maintenance manpower. Estimating methodologies are also similar. Most of the discussion under the manpower cost element is also applicable for material. Unique aspects of material are discussed below. The full set of causative agents and models is shown in Table B.19.

Table B.19

DEPOT MAINTENANCE MATERIAL COST DRIVERS

Driving Factor	Causative Agent	Applicable Models
Reliability & maintainability	Failure rates & modes	LSC-P
Physical characteristics	Aircraft size, number of components	LSC-P DMCE-P[a]
Maintenance concept	Types and amount of work done in depot maintenance	LSC-P
Supply support concept	None	----
Training concept	None	----
AGE concept	None	----
Crew size & composition	No significant effect	----
Force size & activity rate	Number of failures	BACE/CACE-F DMCE-F LSC-F
Basing/deployment concept	None	----
Mission type and profile	Operational reliability	DMCE-P

[a]"DMCE" identifies the AFLC Depot Maintenance Cost Equations.

Cause-Effect Relationships

A number of factors that drive depot maintenance manpower affect depot maintenance material requirements less strongly or not at all. R&M characteristics have less effect—failure rates and modes are significant, but repair times do not drive the amount of material required. Stock levels also have no effect. Investment spares stock levels are unrelated to consumable material requirements, and authorized stock levels for consumables affect the value of the inventory, but not the amount of material actually used in maintenance. Similarly, maintenance material is unrelated to AGE, since material cannot be traded for AGE capability as manpower can. All other driving factors are the same as for depot maintenance manpower.

Applicable Models

The LSC model estimates the cost of depot material by multiplying its computed FLU depot man-hour requirement by a material cost per man-hour. Sensitivity to driving factors is therefore similar to that provided for the depot maintenance manpower cost element, but constrained by the additional assumption that man-hours and material requirements must increase and decrease together. This assumption may be valid at high levels of aggregation even though, as noted above, manpower itself does not drive material consumption. Engine overhaul cost is computed as a total cost, not differentiated between manpower and material costs; and depot maintenance of SRUs and whole aircraft is not addressed by this model.

BACE, CACE, and the AFLCP 173-4 equations do not separate the costs of material and manpower, so the evaluations of these models for depot manpower are equally applicable to material costs.

MATERIAL DISTRIBUTION

Although one can identify potential effects of weapon system design and operating and support concepts on material distribution cost, definite relationships have not been established. Resources dedicated to this function serve many weapon systems; the extent to which an individual system affects the total cost is not well understood.

Cause-Effect Relationships

If an individual weapon system can affect material distribution costs, the effect is probably felt through changes in the number of requisitions submitted or in the number, size, weight, or sensitivity of the requisitioned items. Potential weapon system effects are summarized in Table B.20. The number of requisitions is determined by the number of items requisitioned and by supply policies, such as reorder quantities. The number of items requisitioned is influenced by several driving factors. Component failure rates are significant —both the inherent hardware reliability and the operational reliability, including effects of mission characteristics. Base repair cycle times, a function of R&M characteristics and maintenance concept decisions, drive the number of replacement items to be obtained from supply

Table B.20

MATERIAL DISTRIBUTION COST DRIVERS

Driving Factor	Causative Agent	Applicable Models
Reliability & maintainability	Failure rates, repair cycle times, base condemnation rates	LSC-F
Physical characteristics	Size, weight, sensitivity, and number of components	LSC-F
Maintenance concept	Hardware indenture repaired at base level	LSC-P
Supply support concept	Reorder quantities, number of stock points	None
Training concept	None	----
AGE concept	None	----
Crew size & composition	None	----
Force size & activity rate	Total number of failures	LSC-F
Basing/deployment concept	None	----
Mission type and profile	Operational reliability, aircraft subsystem types	None

rather than from maintenance. The number of different components combines with component failure rates to drive the total number of replacements needed, which is also driven by force size and activity rate.

The characteristics of requisitioned items are driven by the mission and physical features of the aircraft and by the maintenance concept. The mission affects the subsystems used on the aircraft. Avionics, for example, is likely to be more sophisticated on a combat aircraft than on a transport, with more severe requirements for careful handling and packaging. For a given mission there can be considerable variation in the weight and size of the components used, with corresponding differences in the amount and type of packaging material used. Repair level decisions, which select the hardware to be repaired at base level, determine the size and weight of the items to be distributed to the bases.

Applicable Models

The LSC model computes a transportation cost that includes the cost of packing done as part of material distribution. The computed cost is driven by the number of items shipped and the weight of each. Unfortunately, the packing cost cannot be

separated from the shipping charges, since the combined cost is based on a single cost per pound factor provided in the model user's handbook as a standard Air Force value. Validating this factor is not feasible, since it is not readily related to categories used in programming and budgeting. Also, the packing costs associated with material distribution and with base supply cannot be separated. The model provides some sensitivity through its use of the number of FLUs, failure rates, repair cycle times, weights, force size, and the aircraft flying hour program. This merits a rating of fair for the model's coverage of R&M characteristics, physical characteristics, and force size and activity rate. There is some effect of maintenance concept on NRTS rate and other parameters used in the model, but this effect is not explicit. The model is therefore rated poor for sensitivity to maintenance concept. No sensitivity at all is provided for supply support concept and mission type and profile.

MATERIAL MANAGEMENT

There is no evidence that costs in this category are strongly related to weapon system characteristics or to policies of weapon system operations and support. The cost of managing inventories of weapon system related items may be related to the number of items stocked or to the frequency of stock level changes through procurement actions or in response to requisitions. The *potential* causative agents and models applicable to this cost element are summarized in Table B.21.

Cause-Effect Relationships

The number of different items stocked for an aircraft is driven by the number of components on the aircraft. Conceptually, the extent to which the cost of managing these items is associated with the weapon system depends in part on how many of the parts are common to other aircraft, but there is no generally accepted procedure for allocating common inventory management costs. The number of parts requisitioned is influenced by several driving factors. Component failure rates are significant—both the inherent hardware reliability and the effects of mission characteristics. Base repair cycle times, a function of R&M characteristics and maintenance concept decisions, drive the number of replacement items to be obtained from maintenance and thus the number of additional replacements needed from the supply system. The number of different components combines with component failure rates to drive the total number of replacements needed, which is also driven by force size and activity rate. The number of procurement actions is determined by supply support policies and by item failure rates.

Applicable Models

The LSC model computes the cost of entering new items into the inventory and the cost of managing them over the weapon system operating lifetime. Each of these costs is based on a standard cost per item and is computed only for new items. A new weapon system is charged with all of the cost of new items (including all recurring costs) and none of the cost of existing or common items (not even part of the recurring cost). This approach to handling common parts seems unnecessari-

Table B.21

MATERIAL MANAGEMENT COST DRIVERS

Driving Factor	Causative Agent	Applicable Models
Reliability & maintainability	Failure rates, repair cycle times	None
Physical characteristics	Number of aircraft components, commonality	LSC-F
Maintenance concept	Repair level decisions	None
Supply support concept	Reorder quantity, procurement practices	None
Training concept	None	----
AGE concept	None	----
Crew size & composition	None	----
Force size & activity rate	Total number of failures	None
Basing/deployment concept	None	----
Mission type and profile	Operational reliability	None

ly arbitrary. It would be better to allocate at least the recurring management cost to all of the weapon systems using an item.

TECHNICAL SUPPORT

The cost of Technical Support is probably the Depot Supply cost least likely to be driven directly by weapon system characteristics or by operating and support concepts. It is possible, however, that the total Technical Support effort is apportioned among weapon systems based on perceived differences in the weapon systems' need or priority. The specific causative agents and models applicable to this possibility are summarized in Table B.22.

The amount of Technical Support an aircraft receives may vary with R&M characteristics, the number of components, or the types of materials used. The distribution of Technical Support resources among various aircraft may be driven by the relative importance of the missions of the different aircraft. The cost of field service representatives varies with number of bases, although this is a small cost. None of the models addresses Technical Support cost.

Table B.22

TECHNICAL SUPPORT COST DRIVERS

Driving Factor	Causative Agent	Applicable Models
Reliability & maintainability	Overall adequacy of R&M	None
Physical characteristics	Number of components, types of materials	None
Maintenance concept	None	----
Supply support concept	None	----
Training concept	None	----
AGE concept	None	----
Crew size & composition	None	----
Force size & activity rate	Relative number of aircraft	None
Basing/deployment concept	Number of operating sites	None
Mission type and profile	Relative importance of mission	None

SECOND DESTINATION TRANSPORTATION

Second destination transportation cost can be perceived as a requirement stemming from the performance of maintenance. Since the available modes of transportation are fixed by considerations unrelated to individual weapon systems, the driving factors of interest are those that affect the number and weight of items shipped and the locations between which they are shipped. The specific causative agents and models applicable to this cost element are summarized in Table B.23.

Cause-Effect Relationships

The number of parts shipped depends on the number of component failures, which is in turn related to several factors: the number of components, their inherent failure rates and condemnation rates, the effects of mission on reliability, the number of aircraft in the force, and the level of aircraft activity. Base repair capability determines the rate at which unserviceable parts can be restored to serviceable condition and the fraction that will be condemned, thus driving the number of demands on the supply system. The weight of individual components affects the number of pounds to be transported, as do repair level decisions that

Table B.23

SECOND DESTINATION TRANSPORTATION COST DRIVERS

Driving Factor	Causative Agent	Applicable Models
Reliability & maintainability	Failure rates, repair cycle times, base condemnation rates	LSC-F
Physical characteristics	Weight and number of components	LSC-F
Maintenance concept	Hardware indenture repaired at base level	LSC-P
Supply support concept	Safety stock requirements, number of stock points, reorder quantities	None
Training concept	None	----
AGE concept	None	----
Crew size & composition	None	----
Force size & activity rate	Total number of failures	LSC-F
Basing/deployment concept	Operating site locations	LSC-F
Mission type and profile	Operational reliability, aircraft subsystem types	None

determine the indenture level of components to be shipped to and from the bases. Operating site locations drive the distances to be covered. Total safety stock, as driven by policy and the number of stock points, influences the total number of items transported to the base as an initial inventory.

Applicable Models

LSC computes a cost for packing and shipping NRTS FLUs and replacements for NRTS FLUs and FLUs condemned at base level. SRUs are not treated explicitly. The shipping cost appears equivalent to Second Destination Transportation. The packing cost is partly a Material Distribution cost and partly an Installations Support cost, since it is incurred by both AFLC depots and base supply organizations. The packing and shipping costs cannot be separated. The computed cost is driven by the number of FLUs, FLU weights, and the number of failures for a total force flying hour program defined by the user. Other input variables include NRTS rates and separate cost factors for CONUS and overseas bases. These variables

provide fair sensitivity to R&M characteristics, physical characteristics, force size and activity rate, and basing and deployment concept. Sensitivity to maintenance concept is provided through NRTS rates, but this is limited and implicit and is rated as poor coverage. Since there is no clear connection between weapon system transportation costs estimated by the model and Second Destination Transportation funding in the Air Force budget, there is no way of assessing how well the estimate reflects the system's true effect on cost.

INDIVIDUAL TRAINING

The causative agents for individual training are summarized in Table B.24.

Table B.24

INDIVIDUAL TRAINING COST DRIVERS

Driving Factor	Causative Agent	Applicable Models
Reliability & maintainability	Maintenance manpower	BACE/CACE[a] LSC-P
Physical characteristics	Aircraft size, types of materials, maintenance manpower	BACE/CACE[a] LSC-P
Maintenance concept	Amount & types of work done in base level maint., maintenance manpower	BACE/CACE[a] LSC-P
Supply support concept	Maintenance manpower	BACE/CACE[a]
Training concept	OJT, cross training, manpower	BACE/CACE[a] LSC-P
AGE concept	AGE functions and quantities, maintenance manpower	BACE/CACE[a] LSC-P
Crew size & composition	Functions performed by crew, aircrew manpower	BACE/CACE-F
Force size & activity rate	Manpower	BACE/CACE-F LSC-P
Basing/deployment concept	Manpower	BACE/CACE[a]
Mission type and profile	Functions performed by crew, maintenance manpower	BACE/CACE[a]

[a]BACE and CACE provide indirect sensitivity to these driving factors through manpower, which must be provided as input data.

Cause-Effect Relationships

The content of a training program could need tailoring to accommodate aircraft physical characteristics such as overall size or the type of structural material used. Maintenance concept decisions that affect the type or amount of work done in base-level maintenance can also affect the training program content. OJT policies affect the tradeoff between OJT and classroom training. Formal training policies affect the cost of classroom training per course and the relationship between number of courses and number of men (e.g., cross-training). Maintenance training should be consistent with the support equipment that will be available—complex support equipment may call for extensive, expensive training; or the lack of diagnostic equipment may call for more training in theory than would otherwise be needed. Crew composition has an effect on cost of training aircrew replacements; cost per man should vary with the tasks the crew member performs. Mission type (fighter, cargo, etc.) and profile should affect the content of the operator training program and therefore the cost of training at least some aircrew members.

Most of the driving factor classes have another effect on the cost of individual training—they drive the total requirement for weapon system manpower, which determines the number of personnel replacements to be trained. Maintenance manpower is driven by R&M characteristics, physical characteristics, the maintenance concept, supply support, the training concept, the AGE concept, force size and activity rate, the basing and deployment concept, and the mission. Aircrew manpower is driven by the training concept, crew size and composition, force size and activity rate, and the basing and deployment concept. Command staff manpower, security manpower, and other deployed manpower are driven by force size and activity rate, the basing and deployment concept, and mission. Installations support and health care manpower are driven by the other manpower categories. Details of these relationships are described under the discussions of the various manpower cost elements.

Identifying the variable cost of individual training associated with a weapon system is a very complex task. Most individual training is of a general nature, not related to specific weapon systems. Separating fixed and variable costs requires a study of the organization and operation of the training establishment and how it responds to changes in total Air Force training requirements that result from changes in weapon system characteristics or from changes in operating and support policy. The process through which the total requirements are determined may also need to be investigated. To our knowledge, none of the generalized models is based on such studies; and, consequently, none is considered to provide good sensitivity to the true driving factors.

Applicable Models

The BACE, CACE, and LSC models address individual training costs for a weapon system. BACE and CACE use quite different procedures to estimate training costs, although each relies on total weapon system personnel as the sole driver of cost. BACE estimates pay costs and "Miscellaneous Support" costs (the latter using the same factor used for PPE and BOS) for recruit, specialized, and undergraduate flight/navigator training for students and (apparently) variable instruc-

tor and training support personnel.[5] Apparently no training costs are included for non-aircrew officers. CACE estimates the full variable cost of acquisition and training of all PPE/BOS/RPMA personnel, with separate estimation of aircrew and aircraft maintenance personnel training costs. All CACE training costs are based on turnover rates and on cost per graduate factors generated by Air Training Command. The cost coverage of these factors is not described, and no technique is provided for adjusting them to account for changes in the content of the training program or in the techniques used to accomplish the training. Fair sensitivity is provided only to crew size and force size. Aircrew manpower can be computed from crew size and other input data. The user can multiply the computed cost per squadron by the number of squadrons corresponding to the force size he is analyzing. The models' sensitivity to these factors is useful, though limited by the quality of the cost per man factors. Sensitivity to all other driving factors is provided only indirectly, through input manpower levels.

Training cost estimates produced by these models provide an abstract measure of the training cost effect of a system as a function of total system manpower requirements. But these cost figures are quite remote from programming and budgeting processes, and the way in which the costs are derived makes it virtually impossible either to validate the figures or to identify better values to use (because the costs cannot be tracked in the terms used to estimate them). Hence it is difficult to tell if estimated costs or savings could be translated into real budgetary effects.

LSC estimates one portion of Individual Training cost. It computes the cost of formal maintenance training by multiplying the number of personnel needed for maintenance of the force by a turnover rate and a cost/man factor. The turnover rate and the cost factor are provided as input data, so the model is directly sensitive only to variations in maintenance manpower, which is computed with sensitivity to R&M characteristics, physical characteristics, maintenance concept, training concept, AGE concept, and force size and activity rate. The LSC user's handbook suggests that the cost per man should be taken to be equal to the factor for initial training generated by the contractor. Such a value would imply that the cost of continuing training, within the Air Force, is equivalent to the cost of system-peculiar training provided by the contractor for the initial cadre of maintenance personnel. This is improbable, and the cost of general maintenance skill training that is not peculiar to the aircraft would certainly be ignored by this approach.

HEALTH CARE

Cause-Effect Relationships

Health Care cost and its driving factors have not been studied in detail here, but since this function supports military personnel and dependents directly, it is appropriate to assume that the cost of health care is driven by the number of military personnel. This cost is therefore indirectly driven by the factors that affect deployed unit, below depot maintenance, installations support, and training pipe-

[5] The explanation is difficult to follow, and the numbers cannot be tracked all the way through with the information provided in AFR 173-10.

line manpower. Most depot supply and depot maintenance personnel are civilians and therefore do not receive health care services at Air Force expense.

Applicable Models

BACE and CACE estimate the cost of health care in different ways. CACE uses the simplest approach: factors that represent the marginal health cost per officer or airman. The factors are developed by the AF Surgeon General's Office through an unspecified technique. These factors may not be consistent with our definitions of the life cycle cost elements. BACE separates pay and non-pay health costs. AFR 173-10 provides percentage factors that relate medical manpower to the number of PPE/BOS/RPMA personnel. Different factors are given for each command. These factors were obtained from an undescribed analysis based to some extent on AFM 26-3 manpower standards. The pay for these personnel is estimated in BACE using worldwide average pay rates for officers and airmen and a civilian pay rate that varies by command. Non-pay health costs are estimated using a cost per man factor similar to that used by CACE. These models offer direct sensitivity only to crew size and force size. Aircrew manpower can be computed from input crew size and other input data. The user can multiply the computed cost per squadron by the number of squadrons corresponding to the force size he is analyzing. The models' sensitivity to these factors is useful, though limited by the quality of the cost per man factor. Sensitivity to all other driving factors is provided only indirectly, through input values of manpower.

PCS TRAVEL

Cause-Effect Relationships

The number of individuals involved in PCS moves is mainly a result of policy decisions not related to the weapon system. Most moves involve personnel rotation, an Air Force-wide policy. Unit moves also result from policy decisions; these may be related to a change in basing concept, but are normally considered as part of total force planning rather than weapon system decisions.

Since the main drivers are not weapon system related, the PCS cost attributable to an individual system is appropriately assumed to be affected only by the number of people needed to operate and support the system. Using this assumption, PCS cost will vary (indirectly) with those factors that drive deployed unit, below depot maintenance, installations support, training pipeline, and health care manpower. Almost all depot maintenance and depot supply personnel are civilians and therefore generate little PCS travel cost.

Applicable Models

BACE and CACE use PCS cost per man factors to establish the PCS cost associated with a weapon system. Different factors are used for officers and airmen and for CONUS and overseas moves. BACE applies the factors to PPE, installations support, and medical personnel and UPT/UNT trainees. CACE applies the factors to only PPE and installations support personnel. These models offer direct sensitivi-

ty only to crew size and force size. Aircrew manpower can be computed from input crew size and other input data. The user can multiply the computed cost per squadron by the number of squadrons corresponding to the force size he is analyzing. The models' sensitivity to these factors is useful, though limited by the quality of the cost per man factor. Sensitivity to all other driving factors is provided only indirectly, through input values of manpower.

REPLENISHMENT SPARES

This discussion treats the cost of replacement items. For inventory additions, the driving factors are the same as for the LCC category Initial Spares. The specific causative agents and models applicable to true replenishment are summarized in Table B.25.

Table B.25

REPLENISHMENT SPARES COST DRIVERS

Driving Factor	Causative Agent	Applicable Models
Reliability & maintainability	Failure rates and modes of failure	LSC-F
Physical characteristics	Number of components, indenture structure	LSC-P
Maintenance concept	Hardware indenture for base-level condemnation	LSC-P
Supply support concept	None	----
Training concept	None	----
AGE concept	None	----
Crew size & composition	None	----
Force size & activity rate	Number of failures	LSC-F BACE/CACE-F
Basing/deployment concept	None	----
Mission type and profile	Condemnation rate, operational reliability	None

Cause-Effect Relationships

Total spares cost will be driven by number of items on an aircraft, failure rates and modes, and the size and activity rate of the force. Mission profile affects failure

rate and possibly the fraction of failures condemned. The number of replacements needed can vary with the hardware level that is considered to be appropriate for condemnation—the extreme cases are no replenishment (repair everything) and no repair (remove, dispose of, and replace all failed components). The condemnation decision is constrained by the indenture structure of the design, i.e., by the relative numbers of line- and shop-replaceable units.

Applicable Models

Both BACE and CACE use cost per FH factors, which give fair coverage of force size and activity rate. The flying hour rate is an input quantity that drives the cost directly. The models generate cost estimates for single squadrons, which can be multiplied (outside the models) by number of squadrons to provide sensitivity to force size. The cost factors are defined only at the total weapon system level. The BACE factors are peculiar to a given budget year (they apparently are developed by dividing the budget request by programmed flying hours) and may vary erratically from year to year. The CACE factors are described as representing "steady-state" requirements, but the changes in factor values in the periodic updates to AFR 173-10 are great enough to suggest that short-term effects or changes in assumptions can affect them unpredictably. Hence, they are generally unsuitable as a basis for predicting spares costs for future systems and cannot be used at all for addressing problems at the subsystem level.

True replacements for FLUs are modeled by LSC as a function of the failure rates and base condemnation rates, which are mainly R&M characteristics, although they can also implicitly account for some maintenance concept decisions. Scheduled removals, and their effects on total requirements for replacement items, are not considered. Depot condemnations are not treated in the LSC model now, although work is reportedly underway to include them in a revised model. The model addresses FLUs individually, but ignores SRUs. LSC uses the total flying hours for a force size of interest, ignoring the effects of activity measures other than flying hours. It does not account for lateral resupply, depot batch repair, cannibalization, or mission effects.

MODIFICATIONS

The modifications of interest are those adopted to overcome an aircraft's failure to reach or maintain acceptable or expected levels of safety, mission accomplishment, or R&M. These modifications are needed to achieve the operational capability for which the weapon system was procured. Specifically excluded from this cost element, since they are outside the scope of LCC estimates, are those modifications undertaken to provide additional operational capability not called for in the original weapon system specifications.

Cause-Effect Relationships

R&M, physical characteristics, and mission type and profile are factors that reflect the status of the weapon system design with respect to the state of the art. Since pushing the state of the art is apt to increase the number of deficiencies that

need correction, these factors may be expected to drive the need for and cost of pertinent modifications. Force size is also a driving factor, since the cost varies with the number of aircraft modified. The specific causative agents and models applicable to this cost element are summarized in Table B.26.

A satisfactory methodology for modification costs would tie cost directly to the specific R&M, physical, and mission features that influence the occurrence of deficiencies. No available methodology does this, and there is no readily available body of data which could serve as the basis for the development of such a methodology.

Table B.26

MODIFICATIONS COST DRIVERS

Driving Factor	Causative Agent	Applicable Models
Reliability & maintainability	Severe R&M requirements	BACE/CACE-P
Physical characteristics	Complex design features	BACE/CACE-P
Maintenance concept	None	----
Supply support concept	None	----
Training concept	None	----
AGE concept	None	----
Crew size & composition	None	----
Force size & activity rate	Number of aircraft modified	BACE/CACE-F
Basing/deployment concept	None	----
Mission type and profile	Rigorous mission requirements	BACE/CACE-P

Applicable Models

BACE and CACE estimate modification costs using a number of UE, multiplied by a constant fraction of flyaway cost. The constant factor appears to be an arbitrary convention. This procedure provides direct sensitivity—through flyaway cost—to R&M, physical characteristics, and mission type. The latter effect may be perverse (i.e., better R&M implying higher flyaway cost, which would generate higher mod costs), particularly when the estimating technique is applied to individual components or when it is used in the analysis of configuration change proposals. At best, the estimating factor provides a rough estimate, on a forcewide basis, of

the long-term level of effort that will be expended on class IV modifications (safety of flight and correction of deficiencies). In the F&FP, projected modification costs include both class IV mods and other types of mods. This total level of effort is nearly always (for every aircraft system PPE and in every year) considerably larger than that predicted by the BACE/CACE methodology. The BACE/CACE technique may have some utility for overall force sizing decisions, but it is a poor indication of the cost differences between alternatives or changes proposals at the system or subsystem level.

REPLENISHMENT GROUND SUPPORT EQUIPMENT

The specific causative agents and models applicable to this cost element are summarized in Table B.27.

Table B.27

REPLENISHMENT GROUND SUPPORT EQUIPMENT COST DRIVERS

Driving Factor	Causative Agent	Applicable Models
Reliability & maintainability	Aircraft maintenance workload	None
Physical characteristics	Aircraft size & weight	None
Maintenance concept	Preventative maintenance policies, repair work done at each echelon	None
Supply support concept	None	----
Training concept	None	----
AGE concept	Policies on AGE types and quantities	None
Crew size & composition	No significant effect	-----
Force size & activity rate	Aircraft maintenance workload	BACE/CACE-F
Basing/deployment concept	Number of operating sites	None
Mission type and profile	Operational reliability	None

Cause-Effect Relationships

The number of items that will need replacement is related to the total inventory, which is influenced by the aircraft maintenance workload, in turn influenced by R&M characteristics, preventive maintenance procedures, and the distribution of repair work among the various levels of maintenance, force size, activity rate, and the number of operating sites. The workload is also affected by the effect of mission on component reliability. The unit cost of replacements may be related to their size, power, or other features potentially related to the overall physical measurements (size, weight, etc.) of the aircraft. Support equipment policies affect both unit cost and total quantity, both of which influence the cost of replacements. For a given size and weight vehicle, a change in crew size means a change in design that could affect maintenance requirements, but the effect on support equipment should be insignificant.

Applicable Models

BACE and CACE use a cost per UE factor based on average flyaway cost to estimate the cost of common AGE replenishment and common AGE spares. Since flyaway cost is not a causative agent, the only driving factor to which this approach is sensitive is force size. Also, the factors generally appear to be poor predictors of Common AGE costs for aircraft PPEs in the F&FP.

TRAINING ORDNANCE

The specific causative agents and models applicable to this cost element are summarized in Table B.28.

Cause-Effect Relationships

Policies that shape advanced flight training affect the amount of ordnance that will be expended to train a crew in weapons delivery techniques. Force size drives the number of crews to be trained. The type of mission determines what types of ordnance, if any, are needed. Crew composition is related to the amount and type of ordnance expended, but only because both are affected by the mission.

Applicable Models

CACE estimates training ordnance cost as a function of unit equipment and number of crews per aircraft, providing sensitivity to force size. The cost factors used in the model for each aircraft vary by command and by mission within command. The discussion in AFR 173-10 of the cost factor development is too limited to support a full assessment of the validity of the factors. They appear to represent planned or programmed consumption of munitions and missiles at standard costs. The relationship between the factors and current budgets or historical costs (for munitions and AIM/AGM missiles) is obscure. A standard technique for generating factors for new aircraft is not provided. Because of these limitations, the CACE coverage of force size and mission is rated only fair.

Table B.28

TRAINING ORDNANCE COST DRIVERS

Driving Factor	Causative Agent	Applicable Models
Reliability & maintainability	None	----
Physical characteristics	None	----
Maintenance concept	None	----
Supply support concept	None	----
Training concept	Weapons delivery training	None
AGE concept	None	----
Crew size & composition	None	----
Force size & activity rate	Number of crews	CACE-F
Basing/deployment concept	None	----
Mission type and profile	Types of ordnance needed	CACE-F